THEORETICAL PERSPECTIVES FOR LC

1. INTRODUCTION

2. CENTRAL FOCUS

- Higgs mechanism and elw symmetry breaking
- Supersymmetry
- Space-time structure

3. PLATFORM

- Electroweak and strong gauge symmetries
- The top quark

4. CONCLUSIONS

MATERIAL :

ECFA / DESY TESLA TDR Reports
http://www.desy.de:8088/HEP/desy-rep.html

The case for a 500 GeV e^+e^- Linear Collider
J. Bagger et al, hep-ex/00.07.022

Linear Collider Physics
P. Derwent et al, FNAL LC Study group

Physics Opportunities of e^+e^- Linear Colliders
H. Murayama and M.E. Peskin, Ann. Rev. N.P. Sci 46 (1996) 533
hep-ph/96.06.003

Physics with e^+e^- Linear Colliders
E. Accomando et al, Phys. Rep. C299 (1998) 1
hep-ph/97.05.442

Possible Accelerators at CERN beyond LHC
J. Ellis, Lund 1999 Proceedings, hep-ph/99.11.440

Physics with e^+e^- Linear Collider at High Luminosity
P.M. Zerwas, Cargèse Lectures, hep-ph/00.03.221

1. INTRODUCTION

LC target: (1) high-precision coverage of energy range above LEP2 up to ~ 1TeV

scale of elw SB : $v \sim 246$ GeV
complementarity to LHC

(2) energy frontier and high-precision coverage of multi-TeV range in après-LHC era

energy range : ~ 5TeV
[complementarity to LHC - phase 2 ...]

Physics: Higgs mechanism / alternative elw SB

Supersymmetry : SUSY breaking
reconstruction of fund. theory

Space-time structure: exploring extra dimensions

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gauge symmetries of the forces / extended symmetries

Profile of top quark

Comprehensive and high precision coverage of energy range above LEP2 to multi TeV → extrapolations of physics to areas eventually far above those which can be reached directly.

MACHINE DESIGNS :

	$\sqrt{s}$	$\int \mathcal{L}$
JLC / NLC // TESLA	500 GeV 1 // 0.8 TeV	500 fb^{-1} 1 ab^{-1}
CLIC	500 GeV 3 to 5 TeV	500 fb^{-1} 1 ab^{-1}

POLARIZATION :

$\mathbb{P}[e^-] \sim 80\%$

$\mathbb{P}[e^+] \sim 40/60\%$

DIAGNOSTICS

$\longrightarrow \quad \longleftarrow$

$\Rightarrow \quad Z' \quad \Rightarrow$

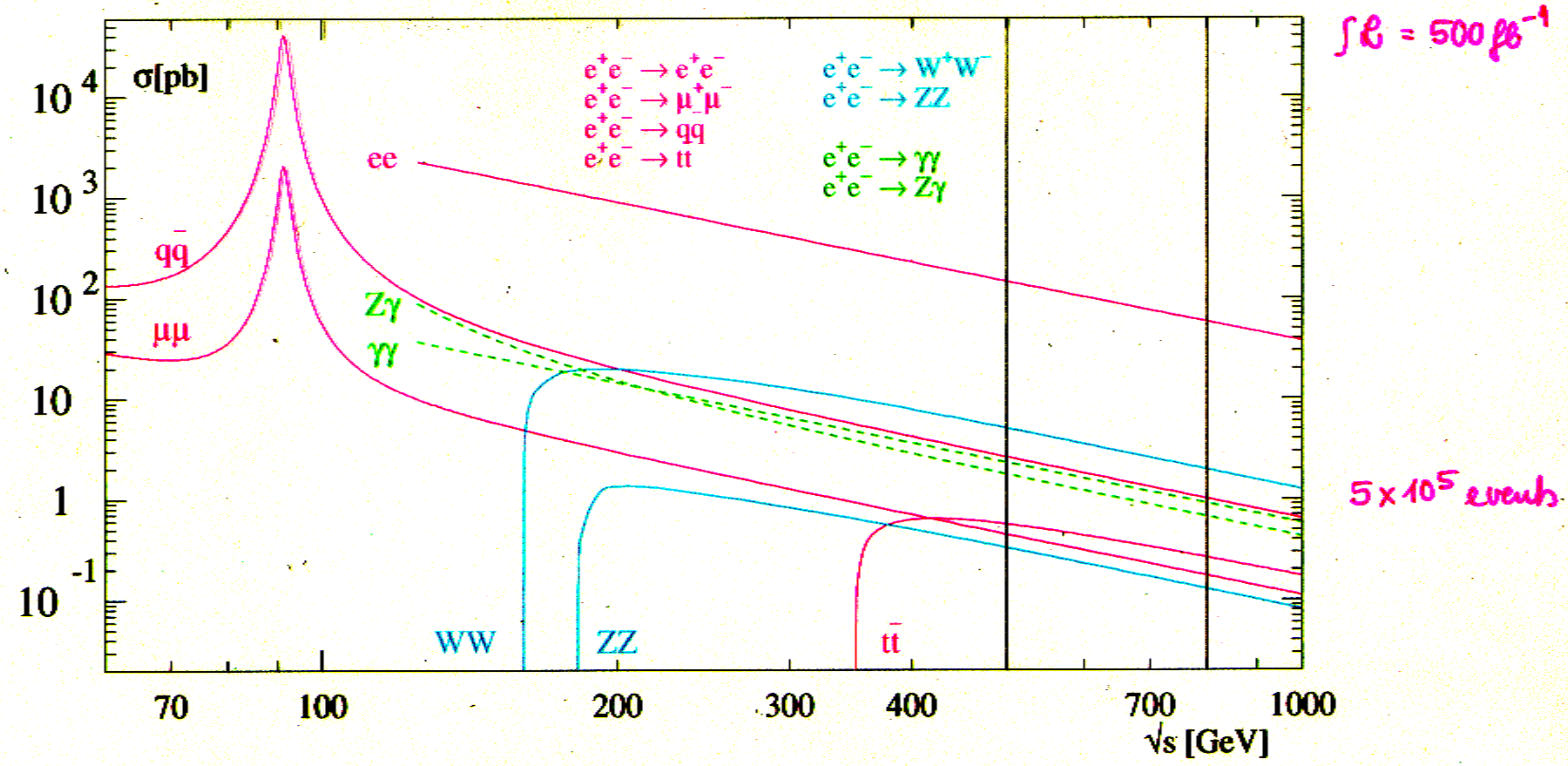
$\Rightarrow \quad \tilde{\nu}_\tau \quad \Leftarrow$

SATELLITE MODES :

	$\sqrt{s}$	$\int \mathcal{L}$
GigaZ	91.187 GeV	2×10^9 Z
e^-e^-	100%	20%
$e\gamma$ $\gamma\gamma$	90% 80%	40% 40%

Linear colliders offer not only high-precision instruments for e^+e^- physics at per-mille level, but also a variety of additional experimental opportunities for dedicated problems.

Pleitz et al


σ[pb]
10^4
10^3
10^2
10
1
10^{-1}
$q\bar{q}$
μμ
ee
Zγ
γγ
WW
ZZ
$t\bar{t}$
$e^+e^- \to e^+e^-$
$e^+e^- \to \mu^+\mu^-$
$e^+e^- \to qq$
$e^+e^- \to tt$
$e^+e^- \to W^+W^-$
$e^+e^- \to ZZ$
$e^+e^- \to \gamma\gamma$
$e^+e^- \to Z\gamma$
70
100
200
300
400
700
1000
√s [GeV]
$\int \mathcal{L} = 500\ fb^{-1}$
5×10^5 events

2a) HIGGS MECHANISM

Theorem: asymptotic unitarity of gauge theories:

$f_{22} \leq 1$ → "light" fund. Higgs boson : $g \ell g \sim$ mass

→ WW strongly interacting : $s > 4\pi\sqrt{2}/G_F \sim (1.2\,\text{TeV})^2$

HIGGS MASS :

Standard Model :
$M_H \lessapprox 200$ GeV

LEPEWWG

Erler, Langacker

(i) radiate elw corrections LEP/SLC/...

$M_H = 86^{+48}_{-32}$ GeV

≤ 194 GeV 95% CL

[missing 2-loop bosonic corrections ...
very likely not significant] F

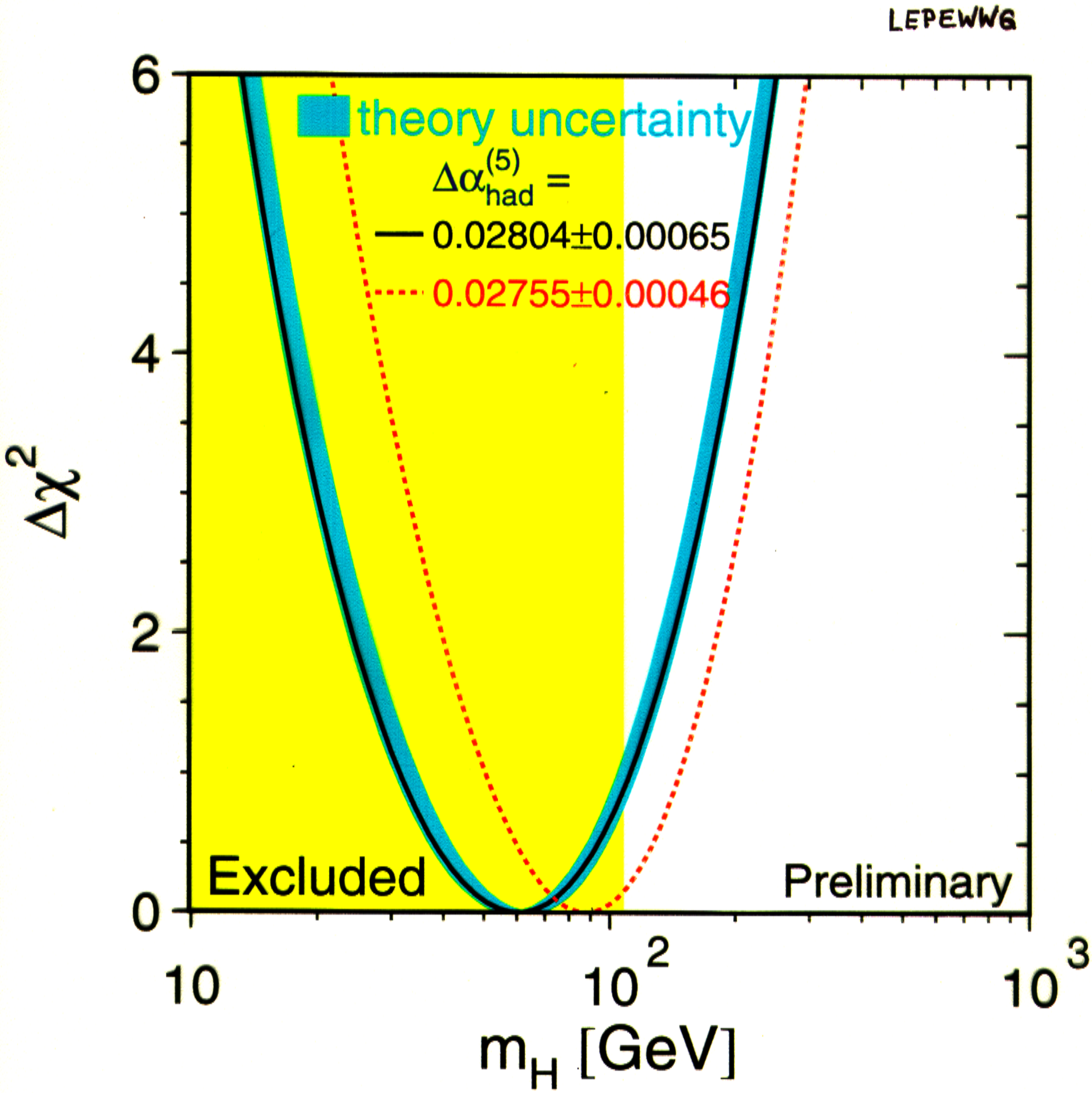
(ii) direct search LEP2 :

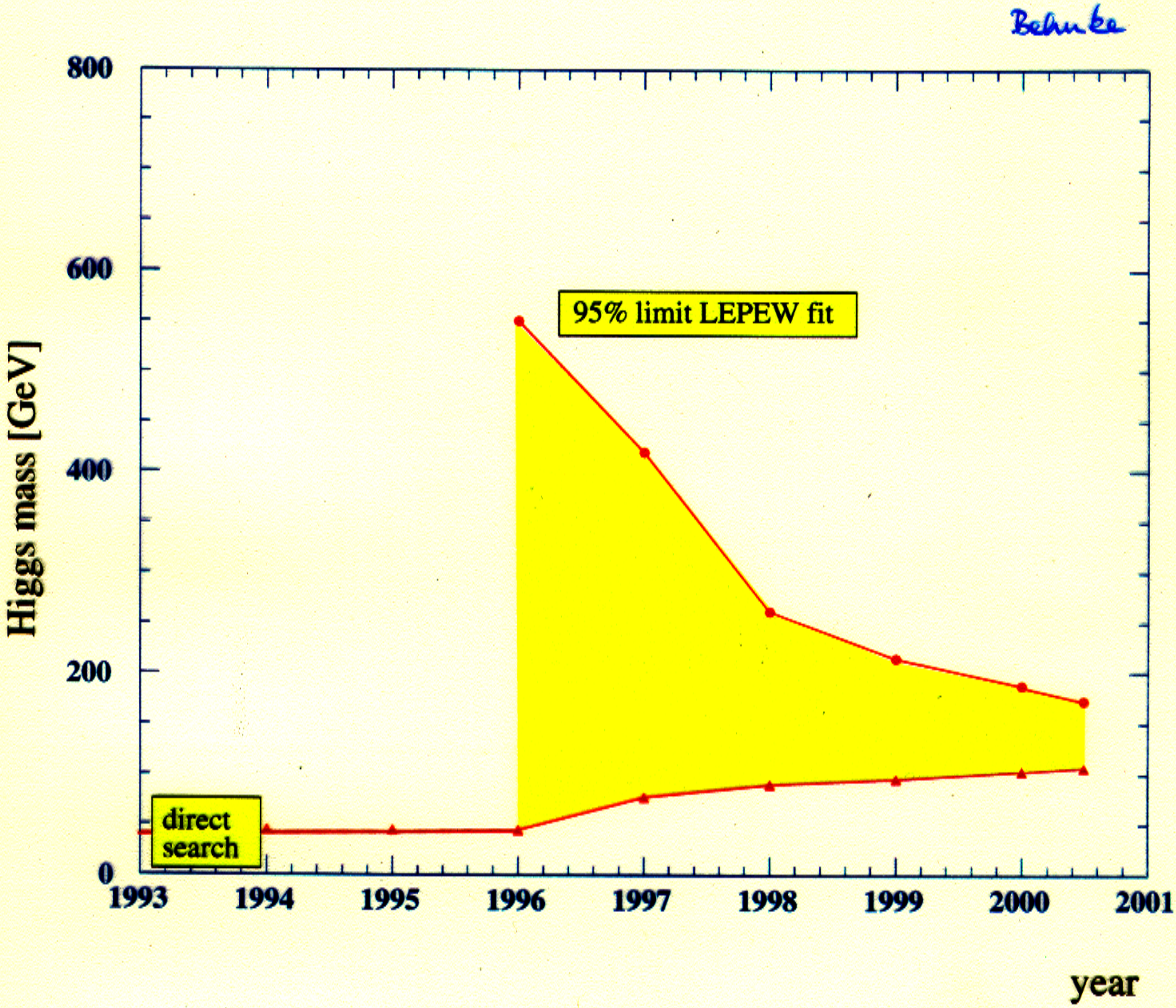
$M_H > 113$ GeV
$M_H \overset{??}{\approx} 115$ GeV

clarification :
next year ?
several years ?

(iii) stability of prediction ?

- $\mathcal{L} = \mathcal{L}_{SM} + \sum \frac{c_i}{\Lambda_i^2} \Theta_i$ ⇒ S, T, U : $M_H \lessapprox 400$ GeV F
- no fundamental Higgs : $\Lambda_* \lessapprox 3$ TeV Bagger et al


LEPEWWG
theory uncertainty
$\Delta\alpha^{(5)}_{had}$ =
0.02804±0.00065
0.02755±0.00046
Excluded
Preliminary
$\Delta\chi^2$
m_H [GeV]
0
2
4
6
10
10^2
10^3



Behnke
800
600
400
200
0
Higgs mass [GeV]
95% limit LEPEW fit
direct search
1993
1994
1995
1996
1997
1998
1999
2000
2001
year

Dimensions six operators	$m_h = 100\,\mathrm{GeV}$		$m_h = 300\,\mathrm{GeV}$		$m_h = 800\,\mathrm{GeV}$	
	$c_i = -1$	$c_i = +1$	$c_i = -1$	$c_i = +1$	$c_i = -1$	$c_i = +1$
$\mathcal{O}_{WB} = (H^\dagger \tau^a H) W^a_{\mu\nu} B_{\mu\nu}$	10	9.7	6.9	—	6.0	—
$\mathcal{O}_H = \lvert H^\dagger D_\mu H \rvert^2$	5.5	4.5	3.7	—	3.2	—
$\mathcal{O}_{LL} = \frac{1}{2}(\bar{L}\gamma_\mu \tau^a L)^2$	8.1	5.9	6.3	—	—	—
$\mathcal{O}'_{HL} = i(H^\dagger D_\mu \tau^a H)(\bar{L}\gamma_\mu \tau^a L)$	8.8	8.3	6.6	—	—	—
$\mathcal{O}'_{HQ} = i(H^\dagger D_\mu \tau^a H)(\bar{Q}\gamma_\mu \tau^a Q)$	6.6	6.9	—	—	—	—
$\mathcal{O}_{HL} = i(H^\dagger D_\mu H)(\bar{L}\gamma_\mu L)$	7.6	8.9	—	—	—	—
$\mathcal{O}_{HQ} = i(H^\dagger D_\mu H)(\bar{Q}\gamma_\mu Q)$	5.7	3.5	—	3.7	—	—
$\mathcal{O}_{HE} = i(H^\dagger D_\mu H)(\bar{E}\gamma_\mu E)$	8.8	7.2	—	7.1	—	—
$\mathcal{O}_{HU} = i(H^\dagger D_\mu H)(\bar{U}\gamma_\mu U)$	2.4	3.3	—	—	—	—
$\mathcal{O}_{HD} = i(H^\dagger D_\mu H)(\bar{D}\gamma_\mu D)$	2.2	2.5	—	—	—	—

Table 1: 95% *lower bounds on* Λ/TeV *for the individual operators and different values of* m_h.

Barbieri
Strumia

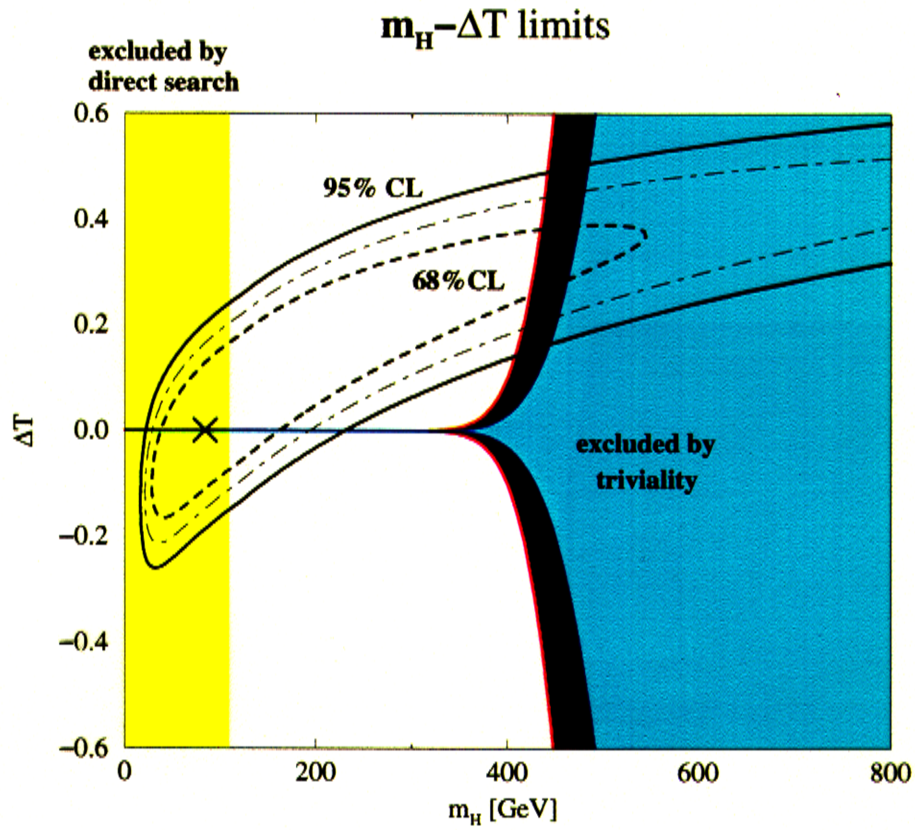


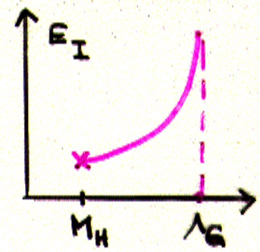
Figure 1: 68% and 95% CL bounds in the $(m_H, \Delta T)$ plane allowed by a fit to precision electroweak data [1, 2]. The best fit "standard model" value is shown by the cross on the $\Delta T = 0$ line. (Also shown by the dot-dash curve is the contour corresponding to $\Delta\chi^2 = 4$, whose intersection with the line $\Delta T = 0$ – at approximately 190 GeV – corresponds to the usual 95% CL upper bound quoted on the Higgs boson mass in the standard model.) The light region to the right is excluded by eqn. 1.3 for $b\kappa^2 = 4\pi$. The dark region denotes the additional area excluded for $b\kappa^2 = 4\pi^2$. The positive branches of the curves bounding these regions are lower bounds for ΔT in the top-seesaw and composite higgs models described in the text. Any $(m_H, \Delta T)$ with positive ΔT and to the left of the appropriate triviality curve can be realized in the corresponding model.

Chivukula et al

GUT:
$M_H \lesssim 180$ GeV

unification elw ⊕ strong :

no strg scale ⇒ $\sin^2\theta_W = 0.2\ldots$



↓

SUSY Higgs:
$M(h^0) \lesssim 180$ GeV

Carena et al.

<u>Higgs spectrum</u> : MSSM : $m(h^0) \lesssim 135$ GeV

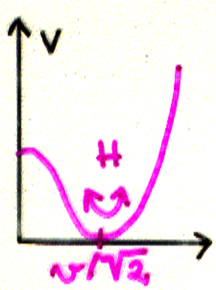
gener. : ext. to M_{GUT}

<u>Summary</u> :

precision data ⊕ $\sin^2\theta_W$ } most naturally accounted for light Higgs mass

SM HIGGS MECHANISM

<u>task</u> : establish Higgs mechanism sui generis for generating masses of fundamental particles

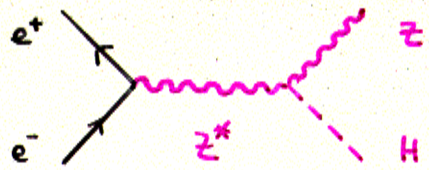


(1) Higgs excitation ≡ <u>Higgs boson</u> must be discovered — LEP2, Tevatron, LHC

(2) generating masses by interaction with Higgs field: <u>couplg ~ mass</u> — [LHC], LC

(3) Higgs field $v/\sqrt{2}$ generated by Spont. Sym. Brkg : <u>reconstruction of Higgs potential</u> — LC

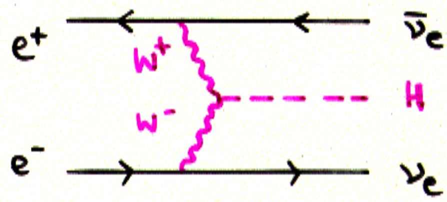
(1) **Higgs-strahlung :**



$\sigma \sim \alpha^2/s$

M_H mod.

WW fusion :



$\sigma \sim \alpha^3/M_W^2$

M_H large

F : $\sqrt{s} \sim 300$ GeV / $\int \mathcal{L} = 500\ fb^{-1}$

$M_H \sim$ intermed. mass range

F : almost background-free

10^5 Higgs bosons

particle param.:

mass	50 MeV	
lifetime - BR_i / Γ_i [i = WW/$\gamma\gamma$]	5-16 %	
spin-parity / CP		Miller, Para, Hagiwara ea

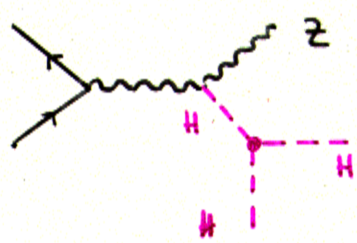
(2)

HZZ, HWW :	prod. / decay	Z/W	
Hff [b, τ, c..] :	decays	b/W	
		b/τ	
Htt :	$e^+e^- \to t\bar{t}H$	b/c	Djouadi ea, Dawson ea, Juste ea

(3) $V = \lambda[\varphi^2 - \frac{1}{2}v^2]^2 = \lambda v^2 H^2$ mass $M_H^2 = 2\lambda v^2$

$+\lambda v H^3 + \frac{\lambda}{4} H^4$ trilin. / quadril. cpl.

HHH : double Higgs-strlg

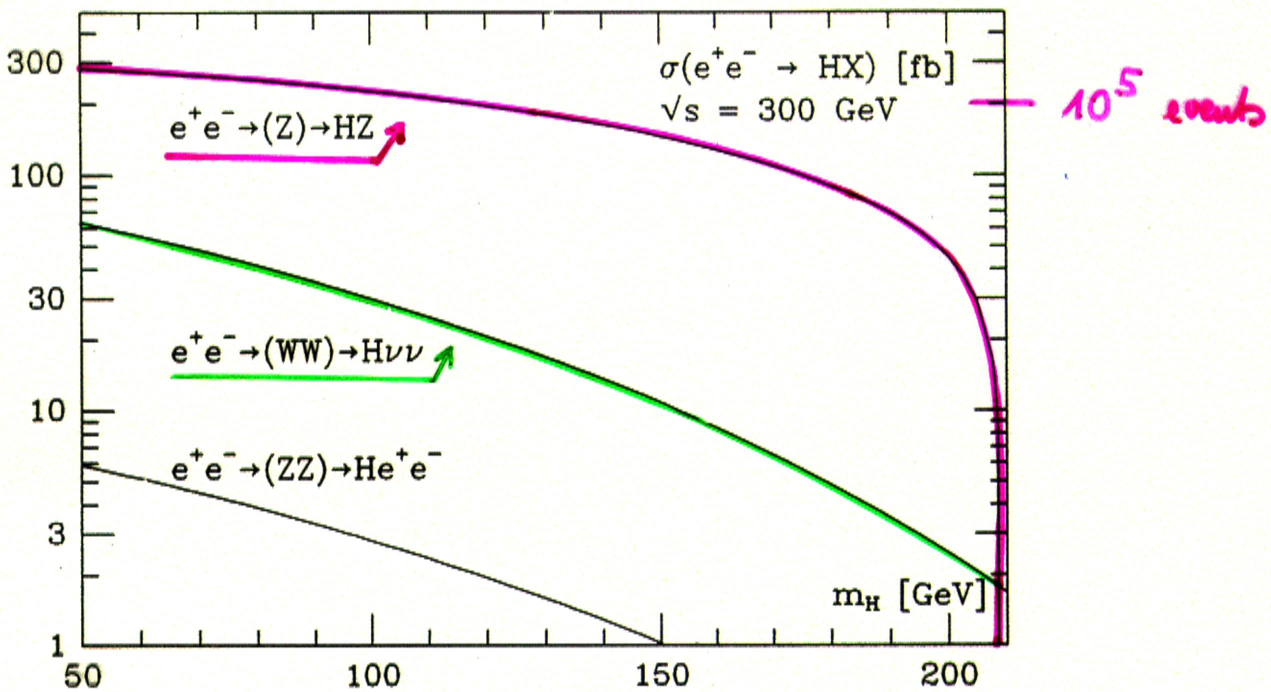


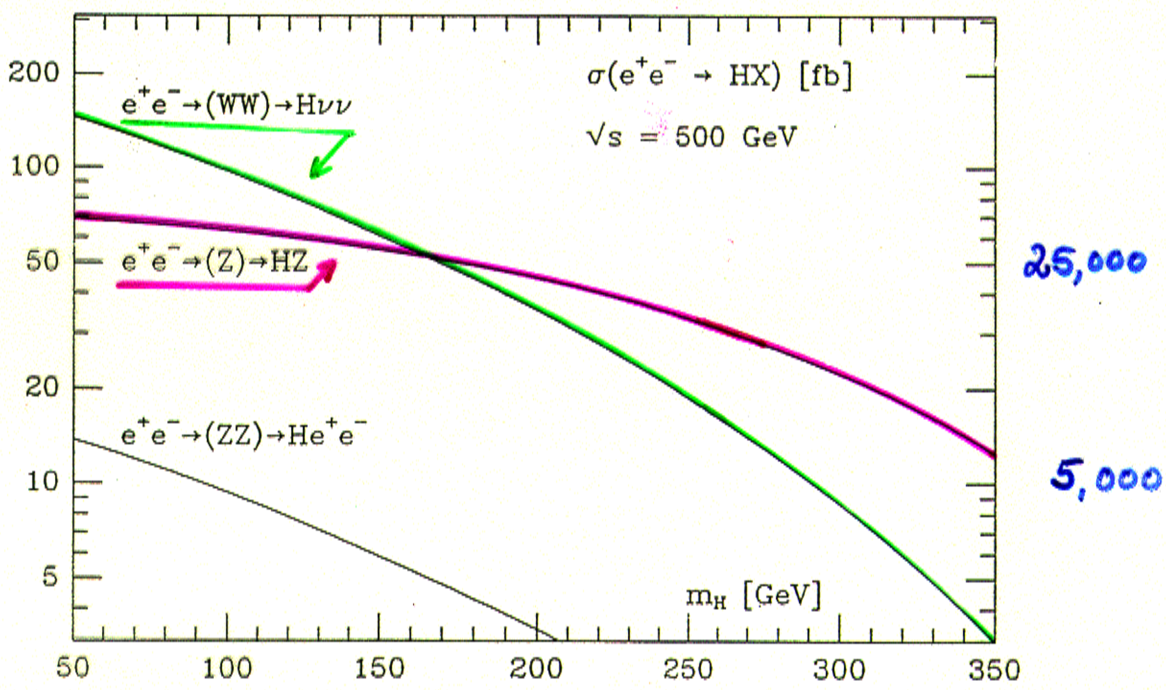
$\sigma \gtrsim$ few 10^{-1} fb

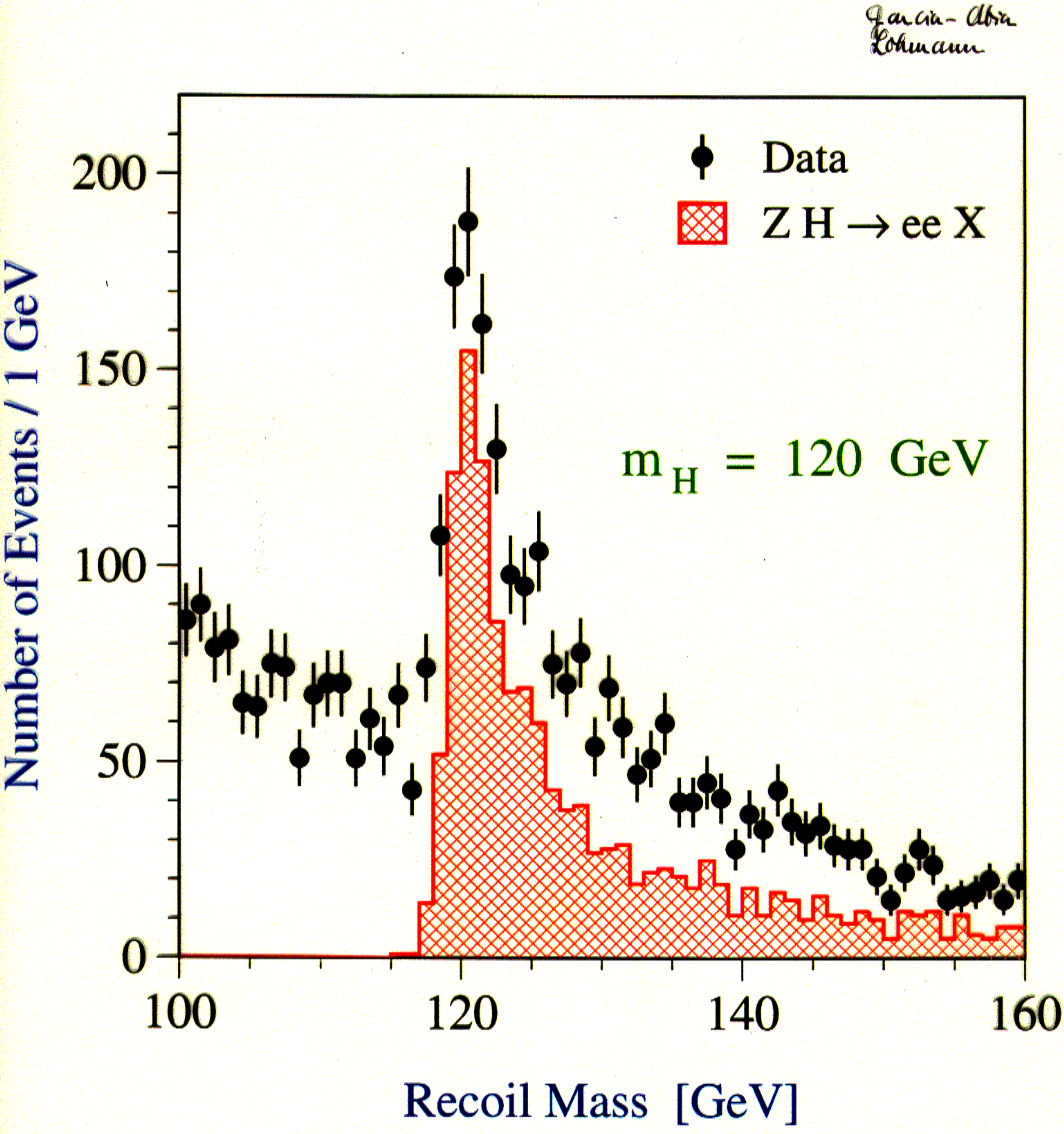
$\Delta\lambda/\lambda \lesssim 18\%$

Djouadi et al

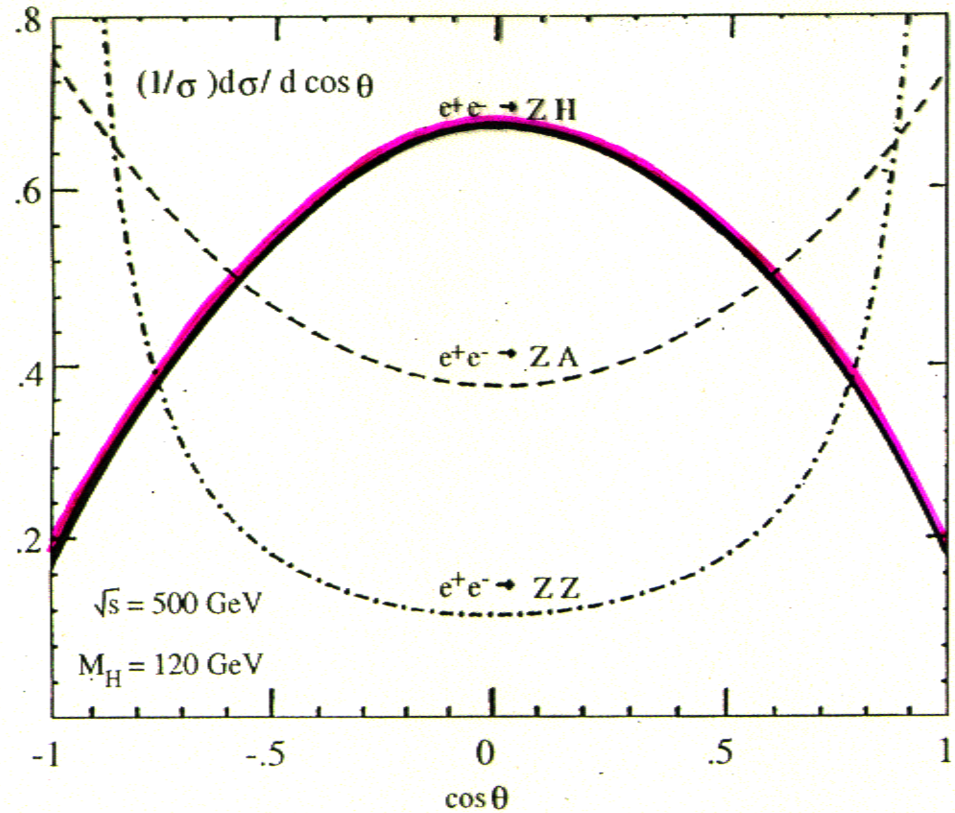
$\int \mathcal{L} = 500\ fb^{-1}$

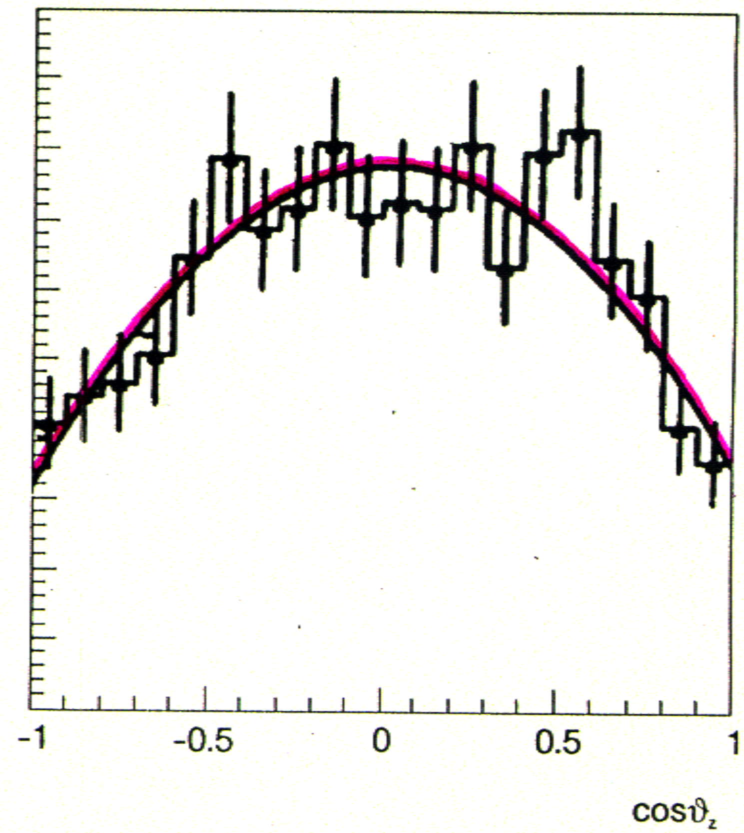


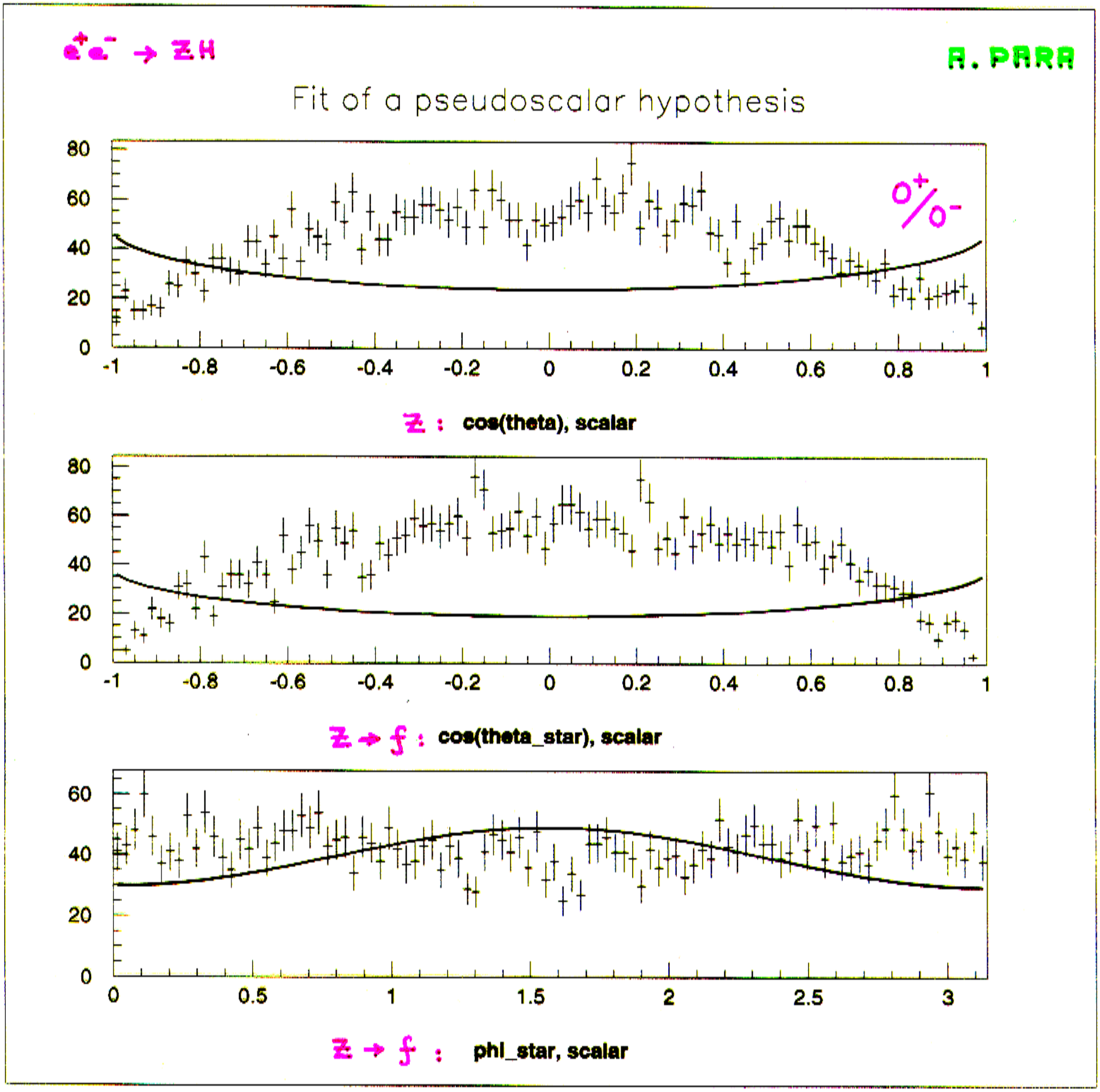




Garcia-Abia
Lohmann
Data
Z H → ee X
m H = 120 GeV
Number of Events / 1 GeV
Recoil Mass [GeV]
0
50
100
150
200
100
120
140
160

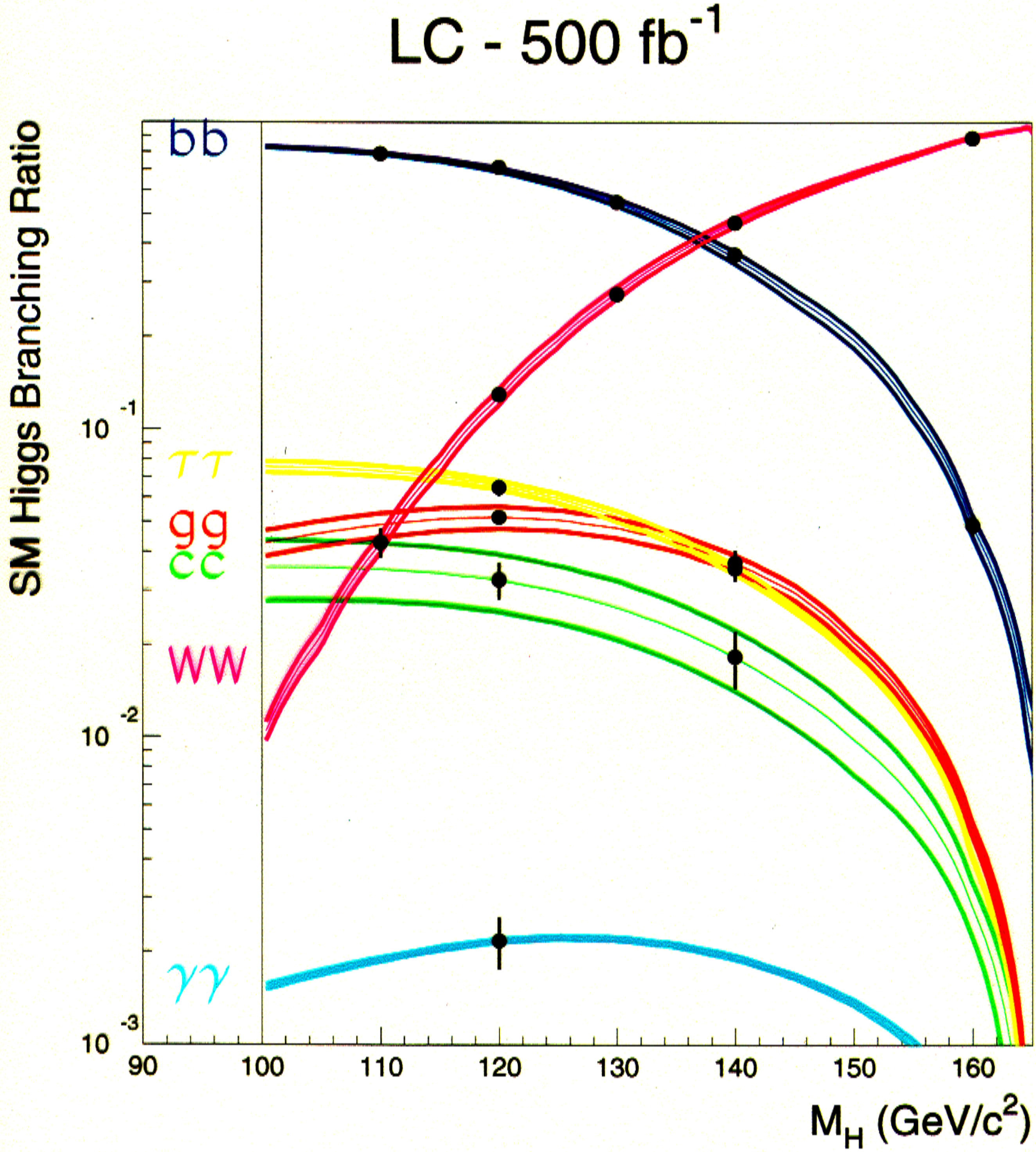

(1/σ)dσ/ d cos θ
e+e- → Z H
e+e- → Z A
e+e- → Z Z
√s = 500 GeV
M_H = 120 GeV
.8
.6
.4
.2
-1
-.5
0
.5
1
cos θ


JLC
-1
-0.5
0
0.5
1
cosϑ_z



e+e- → ZH
A. PARRA
Fit of a pseudoscalar hypothesis
0+/0-
Z : cos(theta), scalar
Z → f : cos(theta_star), scalar
Z → f : phi_star, scalar

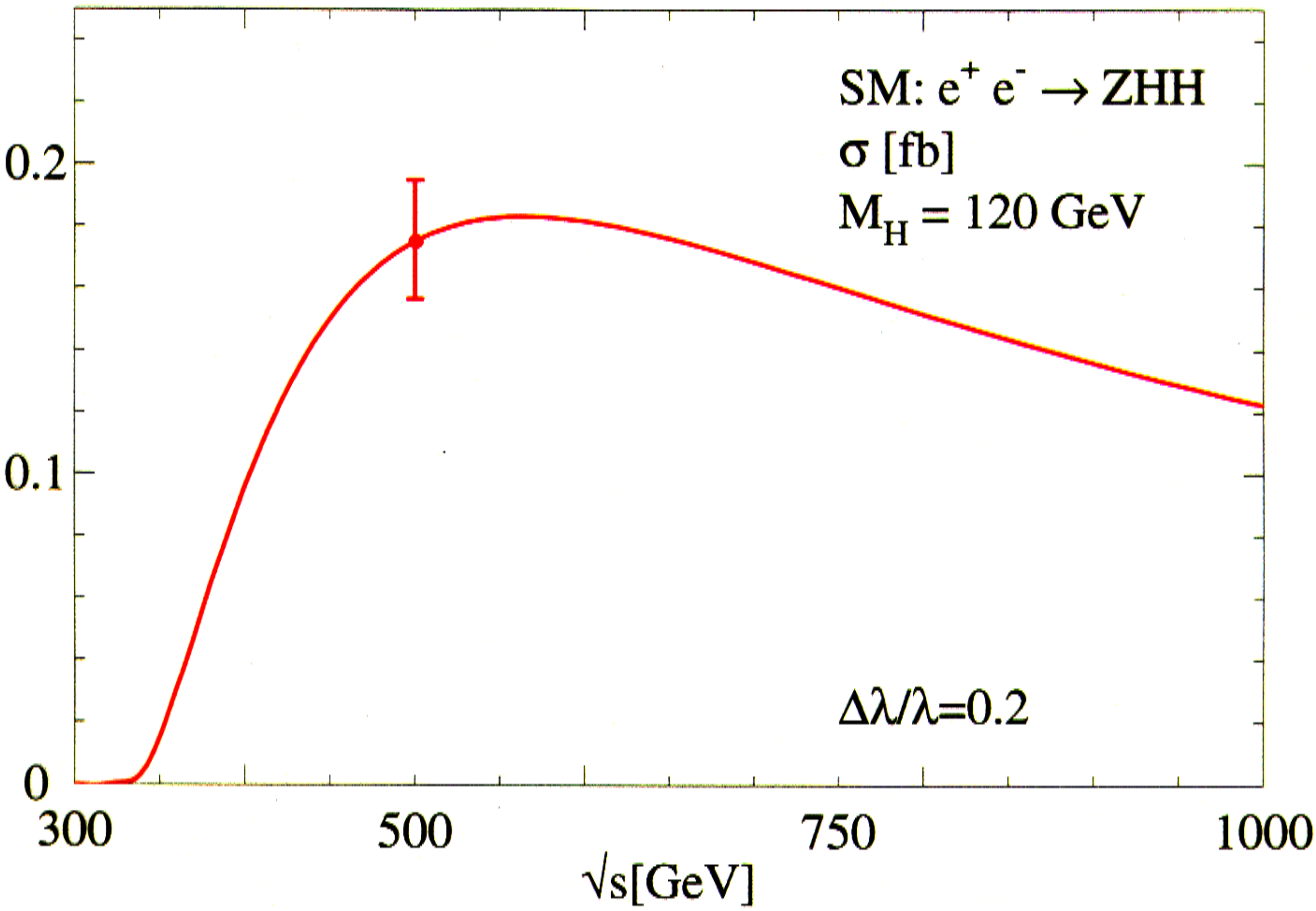
Bataglia



LC - 500 fb^{-1}
SM Higgs Branching Ratio
bb
ττ
gg
cc
WW
γγ
10^{-1}
10^{-2}
10^{-3}
90
100
110
120
130
140
150
160
M_H (GeV/c^2)

Channel	$\delta(BR(H \to X)/BR$	
	CDR Vtx.	Improved Vtx.
$H^0/h^0 \to bb$	$\pm$ 0.024	$\pm$ 0.024
$H^0/h^0 \to c\bar{c}$	$\pm$ 0.135	$\pm$ 0.083
$H^0/h^0 \to gg$	$\pm$ 0.055	$\pm$ 0.055
$H^0/h^0 \to \tau^+\tau^-$	$\pm$ 0.060	
$H^0/h^0 \to WW^*$	$\pm$ 0.054	

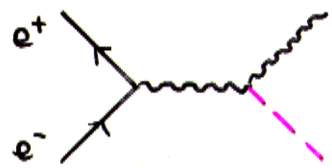
Mühlleitner
Gay, Lutz



SUSY HIGGS BOSONS

spectrum: h^0 $\leq 135/180$ GeV; $H^0, A^0, H^\pm, \ldots$ $\sim \mathcal{O}(v) - \mathcal{O}(\text{TeV})$ } param.: M_A, $tg\beta$

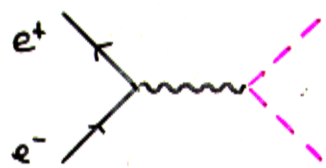
Higgs-strahlung:



$\sigma(Zh) = \sigma_0 \times \sin^2\beta\alpha$

$\sigma(ZH) = \sigma_0 \times \cos^2\beta\alpha$

pair production:



$\sigma(Ah) = \sigma_0 \lambda \times \cos^2\beta\alpha$

$\sigma(AH) = \sigma_0 \lambda \times \sin^2\beta\alpha$

mutual $\sin^2/\cos^2$ coefficients } Zh/Ah cov. ps: h found

M_A small $\leftrightarrow$ $\cos^2$ large } Zh/ZH cov. ps: indep. dec.

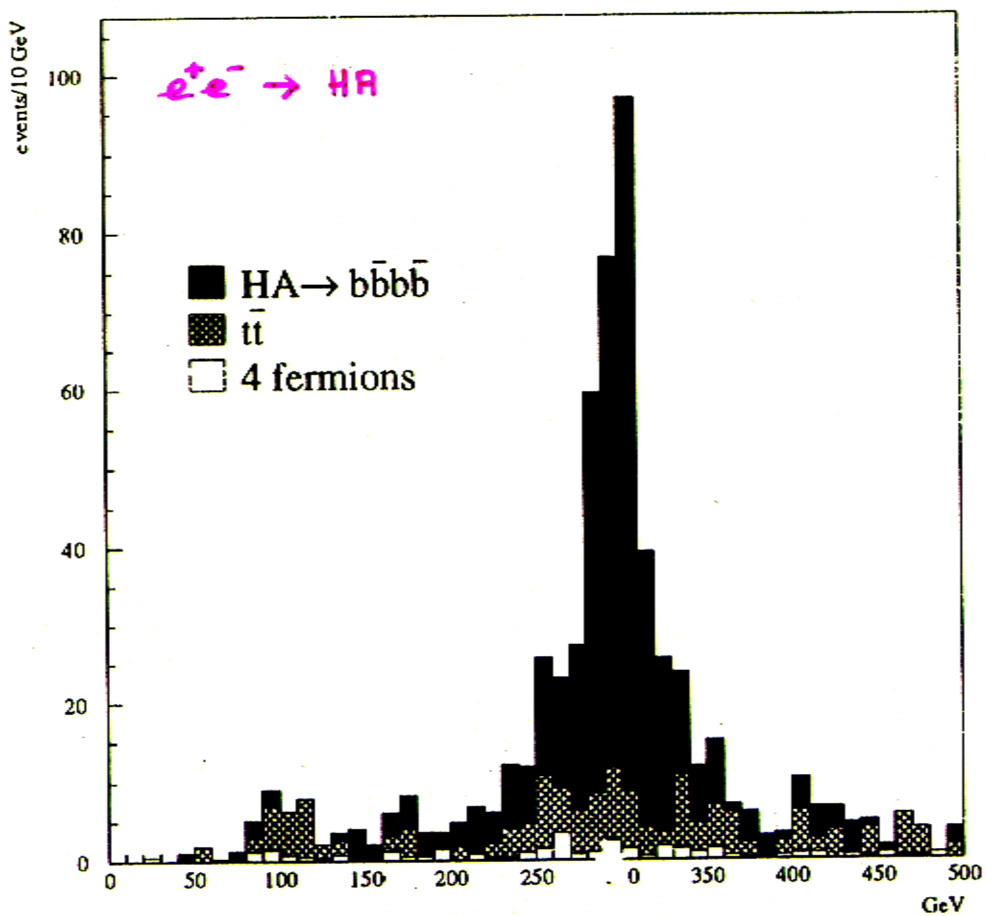
heavy $H, A, H^\pm$: pair production in $e^+e^- \to HA$ and H^+H^- F

LHC probl. > 200-500 GeV F

CLIC acc. up to 2.5 TeV

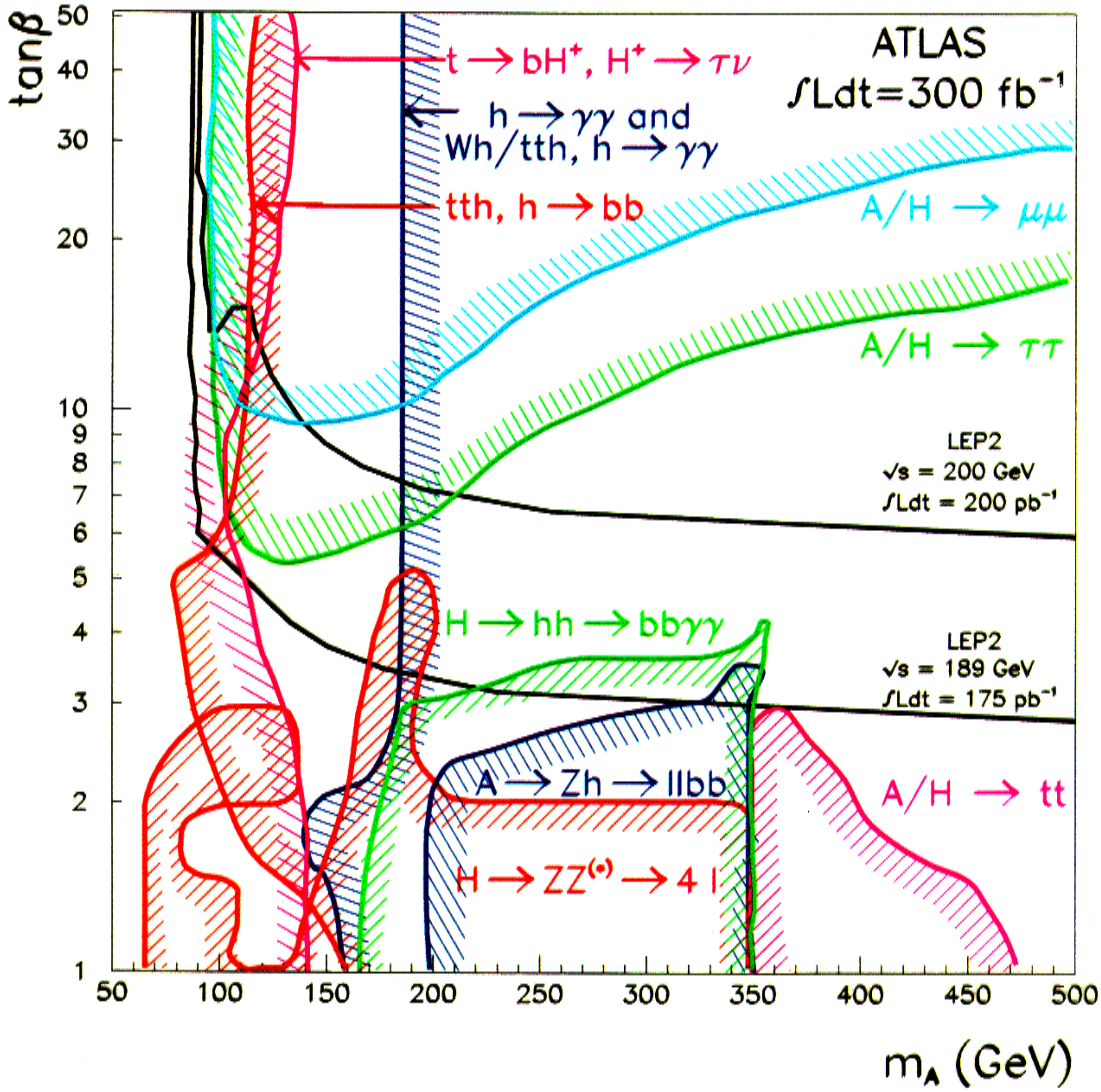
single production in $\gamma\gamma \to A, H$:

LHC dead zone covered F



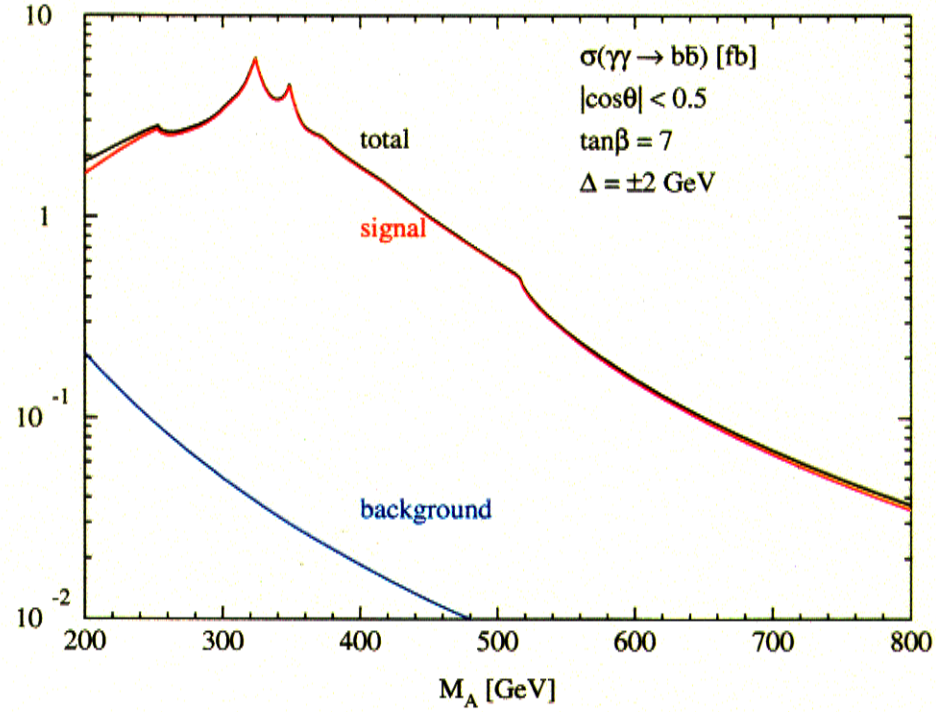
Andreazza

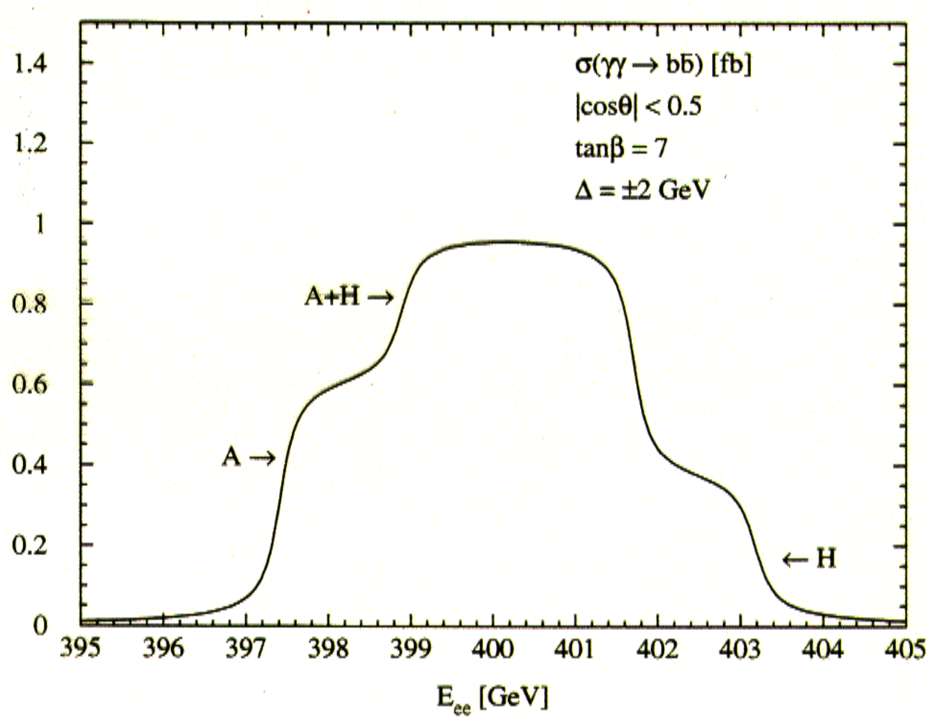
Troncon



ATLAS
∫Ldt=300 fb⁻¹
t → bH⁺, H⁺ → τν
h → γγ and
Wh/tth, h → γγ
tth, h → bb
A/H → μμ
A/H → ττ
LEP2
√s = 200 GeV
∫Ldt = 200 pb⁻¹
H → hh → bbγγ
LEP2
√s = 189 GeV
∫Ldt = 175 pb⁻¹
A → Zh → llbb
A/H → tt
H → ZZ(*) → 4 l
tanβ
m_A (GeV)

Mühlleitner
Krämer, Spira, Z





EXTENDED HIGGS SECTOR : no-lose theorem for discovery :

Ellwanger ea

Espinosa, Gunion

~~lightest~~

↓

second lightest ~ lightest

↓

...

STRONG ELW SYMMETRY BREAKING

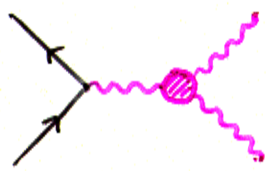
dynamical elw symmetry breaking : new strong interactions Λ_*

chiral sym : spont. broken

Goldstone bosons ~ W_L states

(a) anom. trilin. W cplgs :

Ohl et al



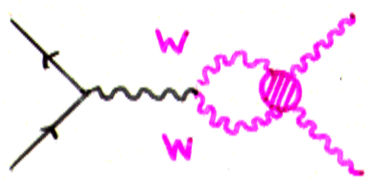
$\sqrt{s} = 500$ GeV

$\Lambda_* \lesssim 3$ TeV

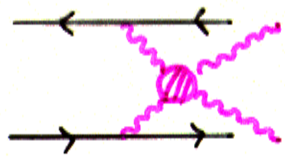
(b) anom. quadril. W cplgs :

Barklow

Boos et al



$M_\zeta \lesssim 2.5$ TeV



$\sqrt{s} = 800$ GeV

$\Lambda_* \lesssim 2.5$ TeV

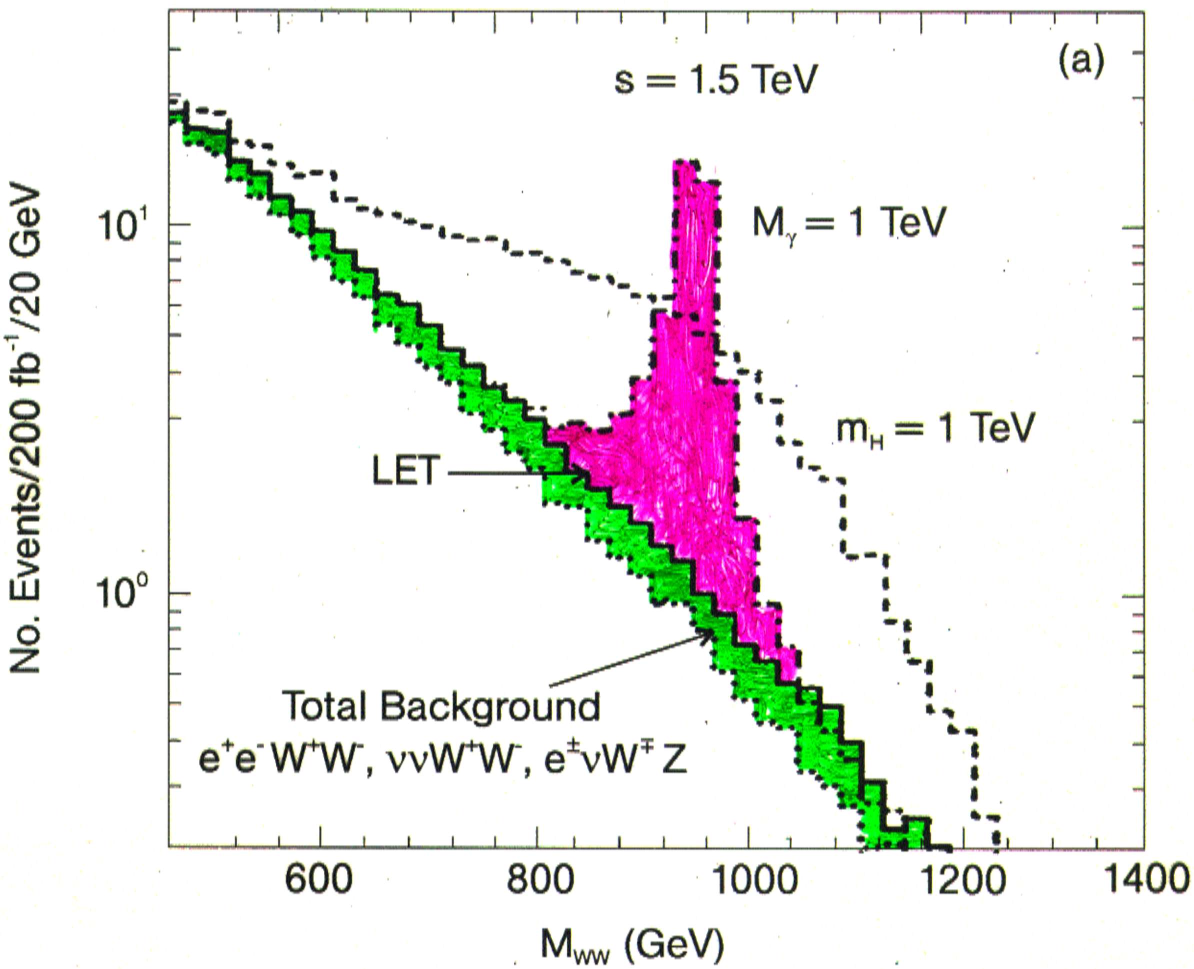
(c) resonance production : in CLIC range

F

(d) pseudo-Goldstone bos. : $\gamma\gamma \to P^0$ $\quad M(P^0) \lesssim 0.7\sqrt{s}$

Casalbuoni et al. $\quad e^+e^- \to \gamma P^0$ $\quad \lesssim 400$ GeV

Banger...



(a)
s = 1.5 TeV
$M_\gamma = 1$ TeV
$m_H = 1$ TeV
LET
Total Background
$e^+e^-W^+W^-$, $\nu\nu W^+W^-$, $e^\pm\nu W^\mp Z$
No. Events/200 fb^{-1}/20 GeV
10^1
10^0
600
800
1000
1200
1400
M_{WW} (GeV)

The strongly interacting W sector, as alternative to the fundamental Higgs mechanism, can be probed:

$\sqrt{s} = 500$ GeV : WW strong threshold region $\Lambda_* \sim 3$ TeV

$\sqrt{s} = 5$ TeV : establishing new resonances / unig.

2(b) SUPERSYMMETRY

SUSY : best motivated extension of Standard Model ✓↗ HP

- connection to gravity
- grand unification:

  $\sin^2\vartheta_W = 0.2335 \pm (17)$

  EXP $= 0.2311 \pm (02)$

MASS SCALE :

- generic solution of hierarchy problem / II : $\tilde{M} \lesssim \mathcal{O}(1\,\text{TeV})$
- "fine tuning" of ehw precision param. : $\tilde{\chi}^{\pm} \lesssim 300-500$ GeV
  ... Feng et al
- estimates from CDM / mod.d.m SUGRA : $\sqrt{s} \lesssim 1.2$ TeV .. 2 TeV
  ... Ellis et al ; Feng et al.
- baryon asymmetry [mod. MSSM] : $m_{\tilde{t}} \lesssim 150$ GeV
  ... Carena et al. $\qquad \mu, M_2 \lesssim 400$ GeV

SUSY DISCOVERY : LEP2 ?

Tevatron

LHC : $m(\tilde{q}, \tilde{g}) \lesssim$ 2 to 3 TeV

$m(\tilde{\chi}) \lesssim$ 200 GeV direct

$m(\tilde{\ell}) \lesssim$ 350 GeV casc: $< m_{\tilde{q}}$ ↑

SUSY EXPLORATION : e^+e^- linear colliders

(1) comprehensive reconstruction of entire SUSY spectrum

- masses
- production and decay
- spin - parity

↓

(2) extract the basic LE parameters :

- gaugino, higgsino, scalar mass parameters, etc.
- wave functions and mixings
- gauge - Yukawa couplings

↓

(3) analysis of SUSY breaking ||

reconstruction of fundam. theory → high scale ~ gravity

LHC analyses : specific paths can be followed
no comprehensive analysis

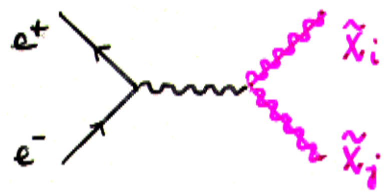
LC analyses : robust / very precise picture
stable extrapol. to high scales

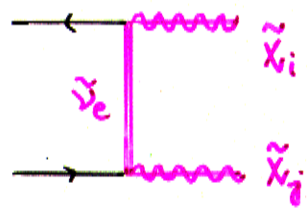
SUPERSYMMETRIC PARTICLES

Production :

Martyn

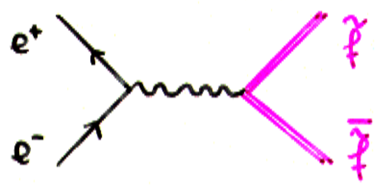
- charginos / neutralinos

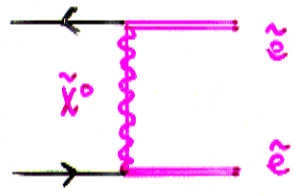




$\sigma \sim \beta$

- sleptons / squarks





$\sigma \sim \beta^3$ / β

DECAYS :

$\tilde{\chi}_i \rightarrow W + \tilde{\chi}^0_1$ $\oplus$ n cascade

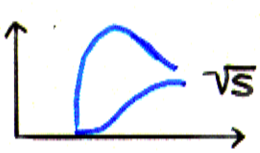
$\tilde{\ell} \rightarrow \ell + \tilde{\chi}^0_1$

$\tilde{q} \rightarrow q + \tilde{\chi}^0_1$

MASSES :

spectral endpts in continuum

scan near prod threshold F



	end pt	thresh
$\tilde{\chi}$	200/300	40/500
$\tilde{\ell}$	200/300	70/600
$\tilde{q}$	~3 GeV	~ 1 GeV

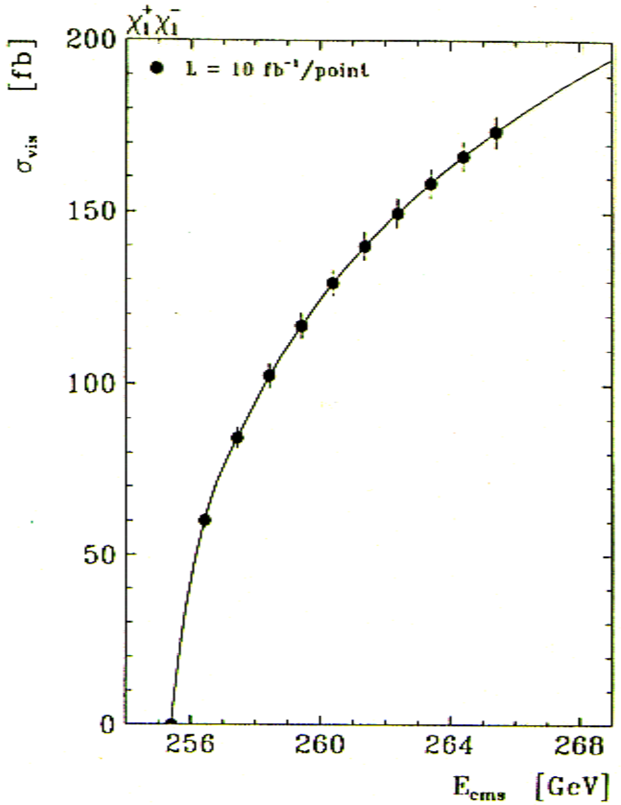
MIXING :

$\tilde{\chi}_i = \alpha_{ij} \tilde{W}_j + \beta_{ij} \tilde{H}_j$ pol $e^\pm$: F Feng ea Kalinowski

$\tilde{t}_i = \alpha_{iL} \tilde{t}_L + \beta_{iR} \tilde{t}_R$ F Kraml ea

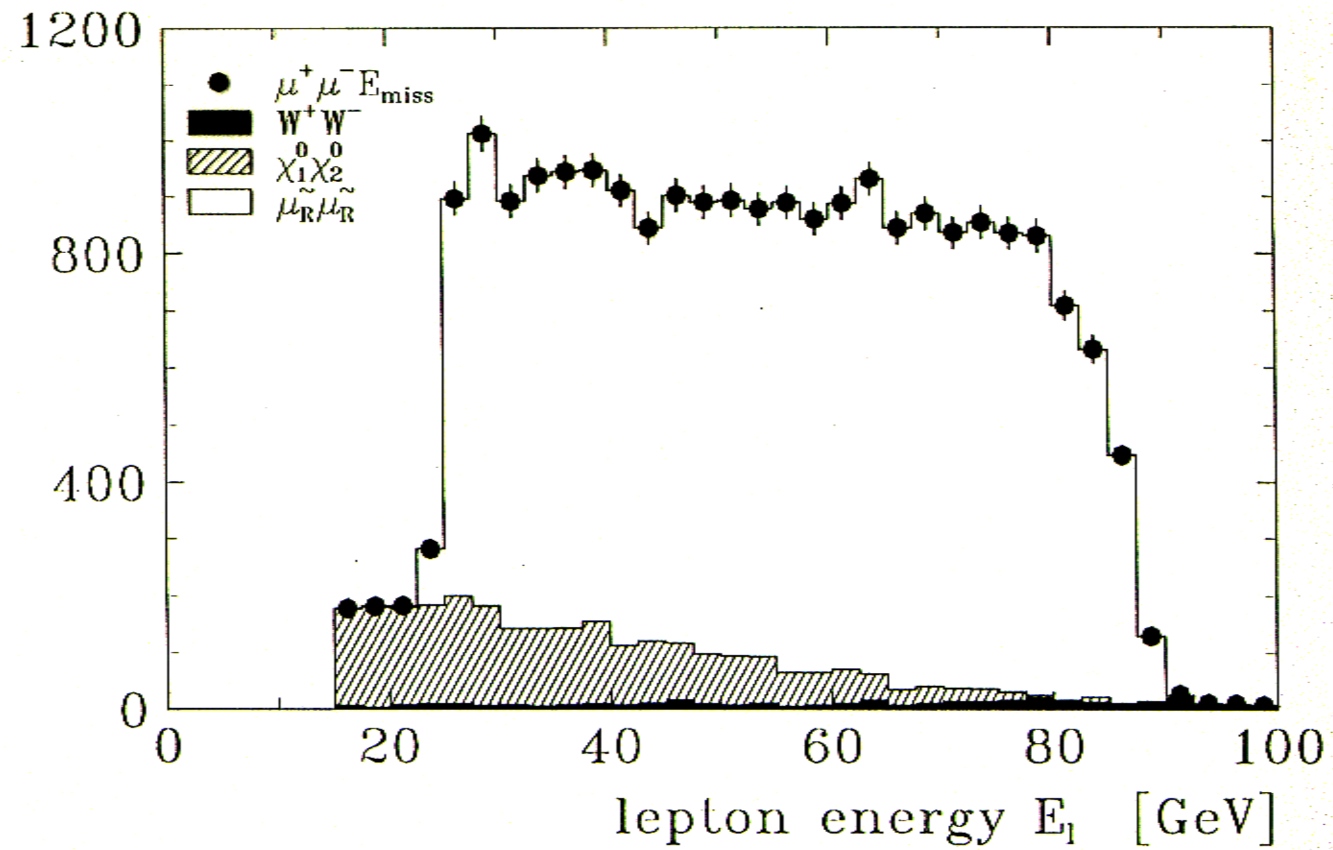
etc.

$e_L^- e_R^+ \rightarrow \chi_1^- \chi_1^+$



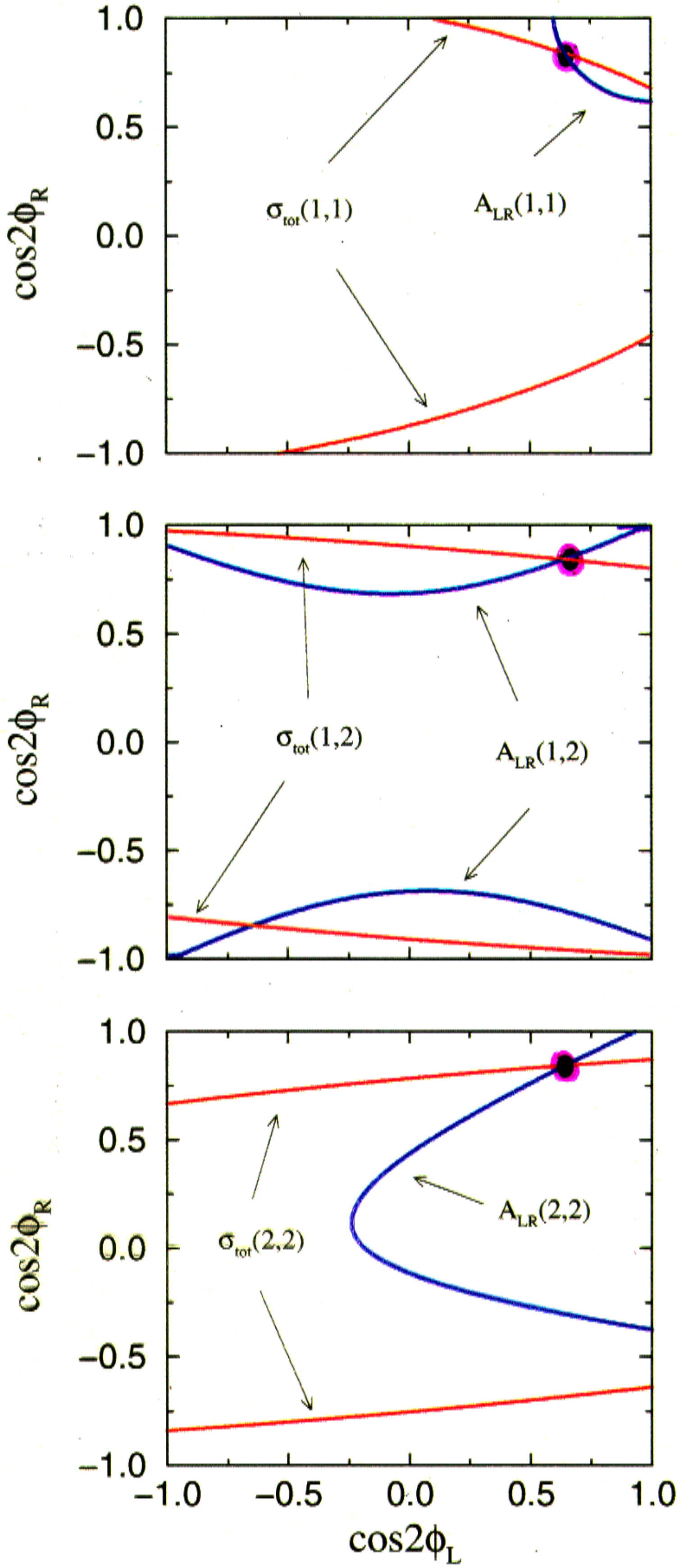
$m_{\chi_1^\pm} = 127.7 \pm 0.04$ GeV

$e^+e^- \rightarrow \tilde{\mu}_R^+ \tilde{\mu}_R^-$



$m_{\tilde{\mu}_R} = 132.0 \pm 0.3$ GeV $m_{\chi_1^0} = 71.9 \pm 0.2$ GeV

Martyn



Choi, Song, Djouadi, Z.

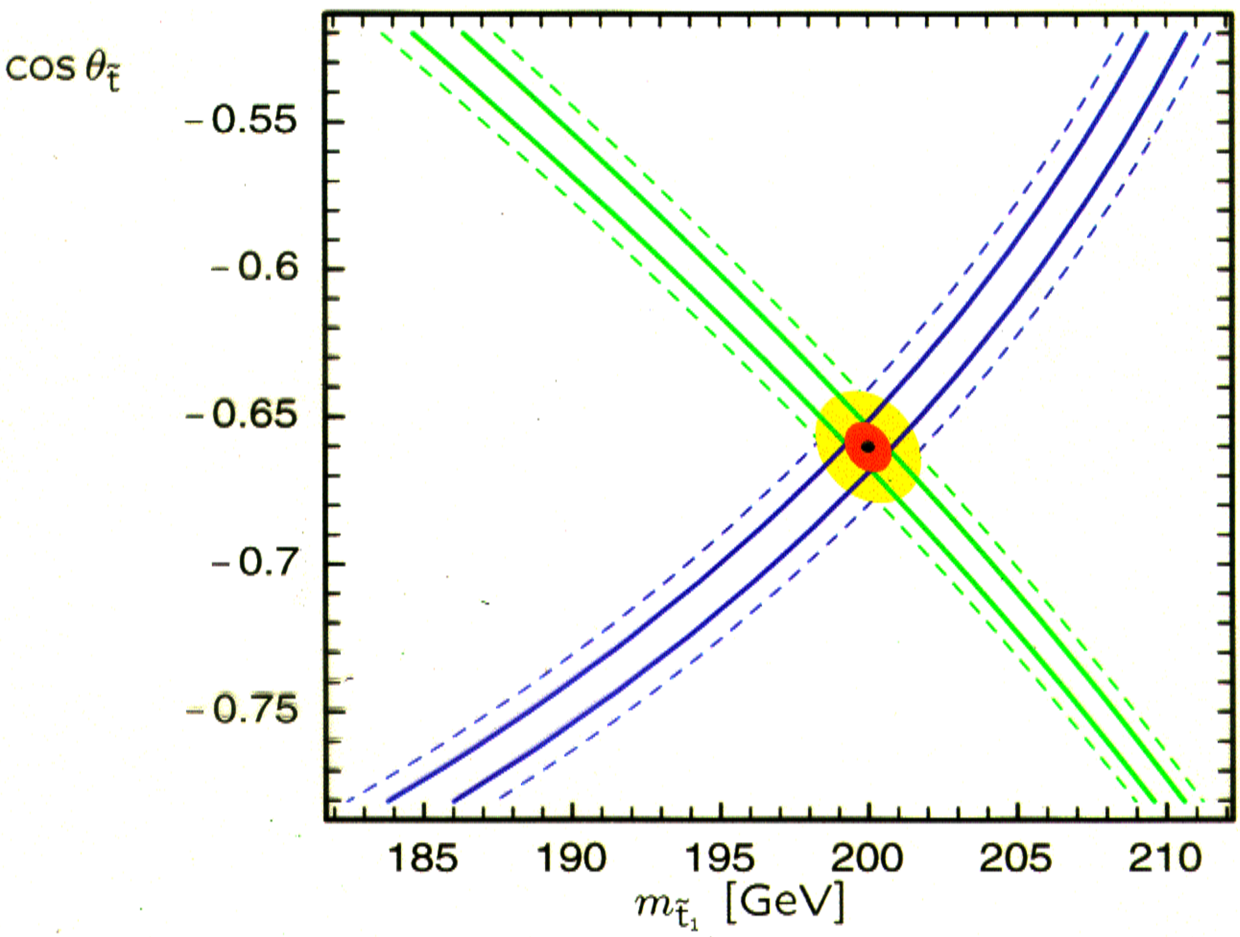
Information on parameters in $\tilde{t}$ sector from direct production at high luminosity LC:

Determination of $m_{\tilde{t}_1}$ and $\theta_{\tilde{t}}$ in $e^+e^- \to \tilde{t}_1\tilde{t}_1$ with 90% polarized e^- beams, $\sqrt{s} = 500$ GeV

[A. Bartl, H. Eberl, S. Kraml, W. Majerotto, W. Porod '99]

Two cases: $\mathcal{L} = 100$ fb^{-1}, $\mathcal{L} = 500$ fb^{-1}

$\mathcal{P}_L = -0.9$: $\sigma_L = 44.88$ fb, $\Delta\sigma_L = 1.73,\ 0.77$ fb
$\mathcal{P}_R = +0.9$: $\sigma_R = 26.95$ fb, $\Delta\sigma_R = 1.34,\ 0.6$ fb

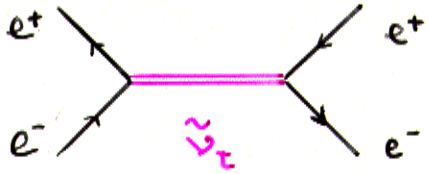


$m_{\tilde{t}_2} = 420$ GeV, $M = 200$ GeV, $\tan\beta = 4$, ...

$\Rightarrow$ direct/indirect information is complementary

very sensitive test of the model

R – PARITY:



Bhabha scattering: R

F

BASIC SUSY LE PARAMETERS

M_1, M_2, M_3	gaugino param.
μ	higgsino param
$m_0, \ldots$	scalar param
A's	bilin. superpot

yukawa cplg ~ gauge cplgs

...

$$M_2/|\mu| = \tfrac{1}{2}\left[2(\chi_2+\chi_1-2W) \mp (\chi_2-\chi_1)(C_{2R}+C_{2L})\right]^{1/2}$$

$$M_1^2 = \Sigma \chi_i^0 - M_2^2 - \mu^2 - 2Z$$

$$tg\beta = \left[4W + (\chi_2-\chi_1)(C_{2R}-C_{2L})\right]^{1/2} / \left[-\right]^{1/2}$$

	measurem. [RR1]
M_2	152 ± 1.8 GeV
M_1	72 ± 3.2 GeV
M_3	[452 ± 10 GeV]
μ	316 ± 0.9 GeV
$m_{0\ell}$	237 ± 0.1 GeV
m_{0q}	460 ± 0.6 GeV
A_t	587 ± 35 GeV
$\tilde{g}/g$	elw: 1 – 2%
$tg\beta$	3.0 ± 0.7

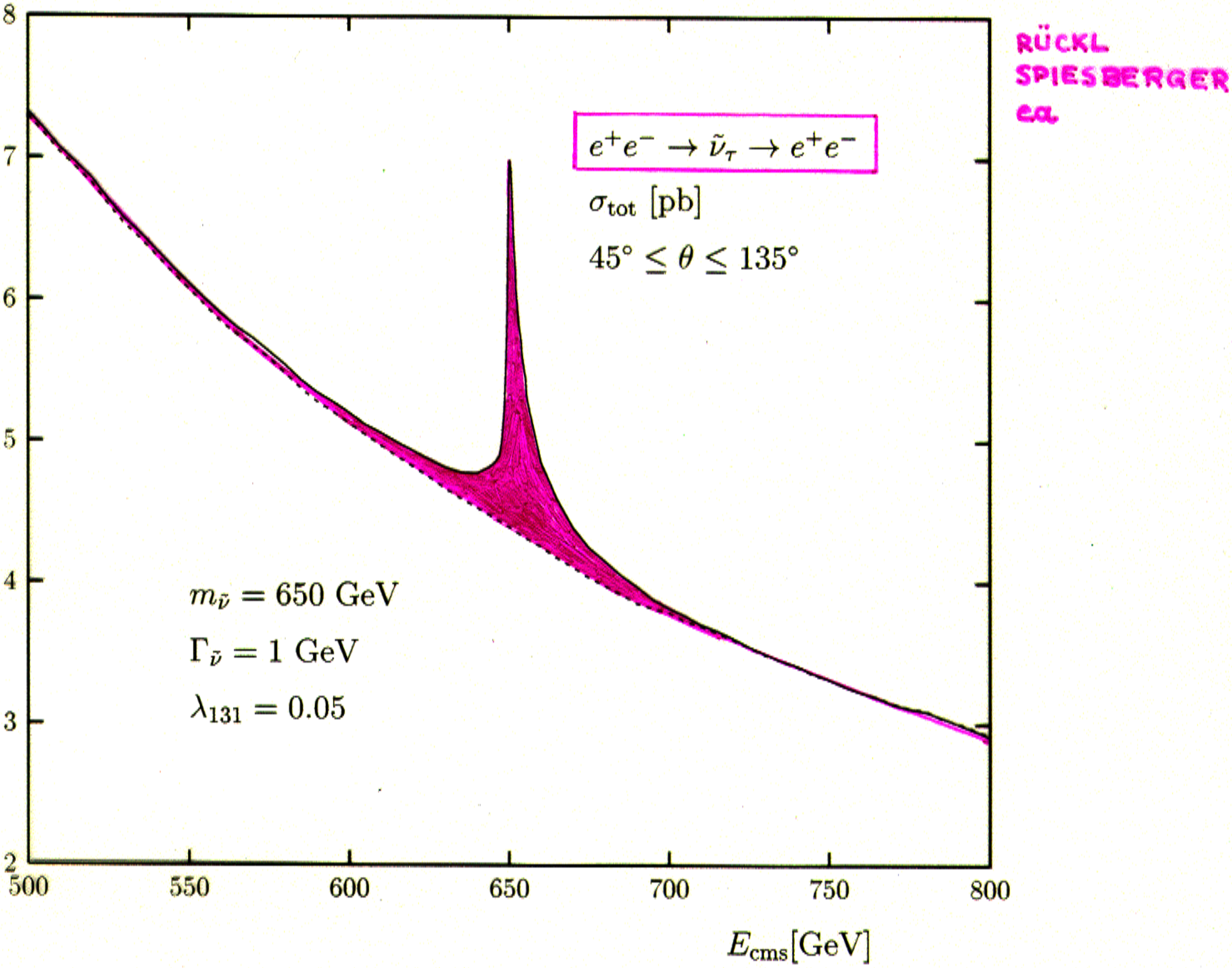
Bartl, Kalinowski, Nojiri ea., Plehn

SUSY BRKG MECH / RECONSTR. FUND. THEORY

physics potential: theor. unsolved won / need won fund. problem

clues on: gravity at small distances

extra space dimensions ...



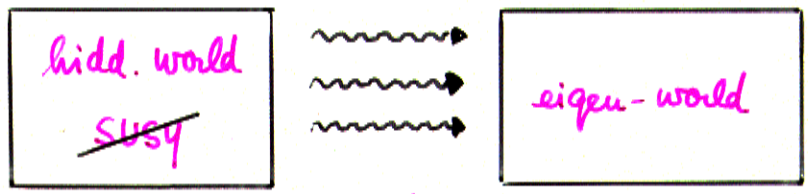
RÜCKL
SPIESBERGER
ea
$e^+e^- \to \tilde{\nu}_\tau \to e^+e^-$
σ_{tot} [pb]
$45° \leq \theta \leq 135°$
$m_{\tilde{\nu}} = 650$ GeV
$\Gamma_{\tilde{\nu}} = 1$ GeV
$\lambda_{131} = 0.05$
8
7
6
5
4
3
2
500
550
600
650
700
750
800
E_{cms}[GeV]

realizations:

mSUGRA	min supergravity
AMSB	
$\tilde{g}$MSB	gaugino med. SB
GMSB	gauge med. SB
SSSB	

...

mechanisms:



$M_{PL} \sim 10^{19}$ GeV — gravity

$M_m \sim 10^{6}$ GeV — gaugino, gauge

(i) [Fairly] characteristic mass pattern: Peskin

F

	gaugino M_i	scalar m_f^2
mSUGRA	$\frac{\alpha_i}{\alpha_2} M_2$	$m_0^2 + \sum_i 2C_i \frac{\alpha_i^2-\alpha_U^2}{b_i \cdot \alpha_2^2} M_2^2$
$\tilde{g}$MSB	$\frac{\alpha_i}{\alpha_2} M_2$	without m_0^2 ~
GMSB	$\frac{\alpha_i}{\alpha_2} M_2$	$\sum_i 2C_i \frac{\alpha_i^2}{\alpha_2^2} M_2^2$
AMSB	$\frac{b_i}{b_2}\frac{\alpha_i}{\alpha_2} M_2$	$\dots + \sum 2\eta_{fi} b_i \frac{\alpha_i^2}{\alpha_2^2} M_2^2$

(ii) Characteristic decay pattern: Auhoriano Gunion ea

GMSB:

$\tilde{\chi}_1^0 \to \gamma + \tilde{G} = \gamma + \not{E}$

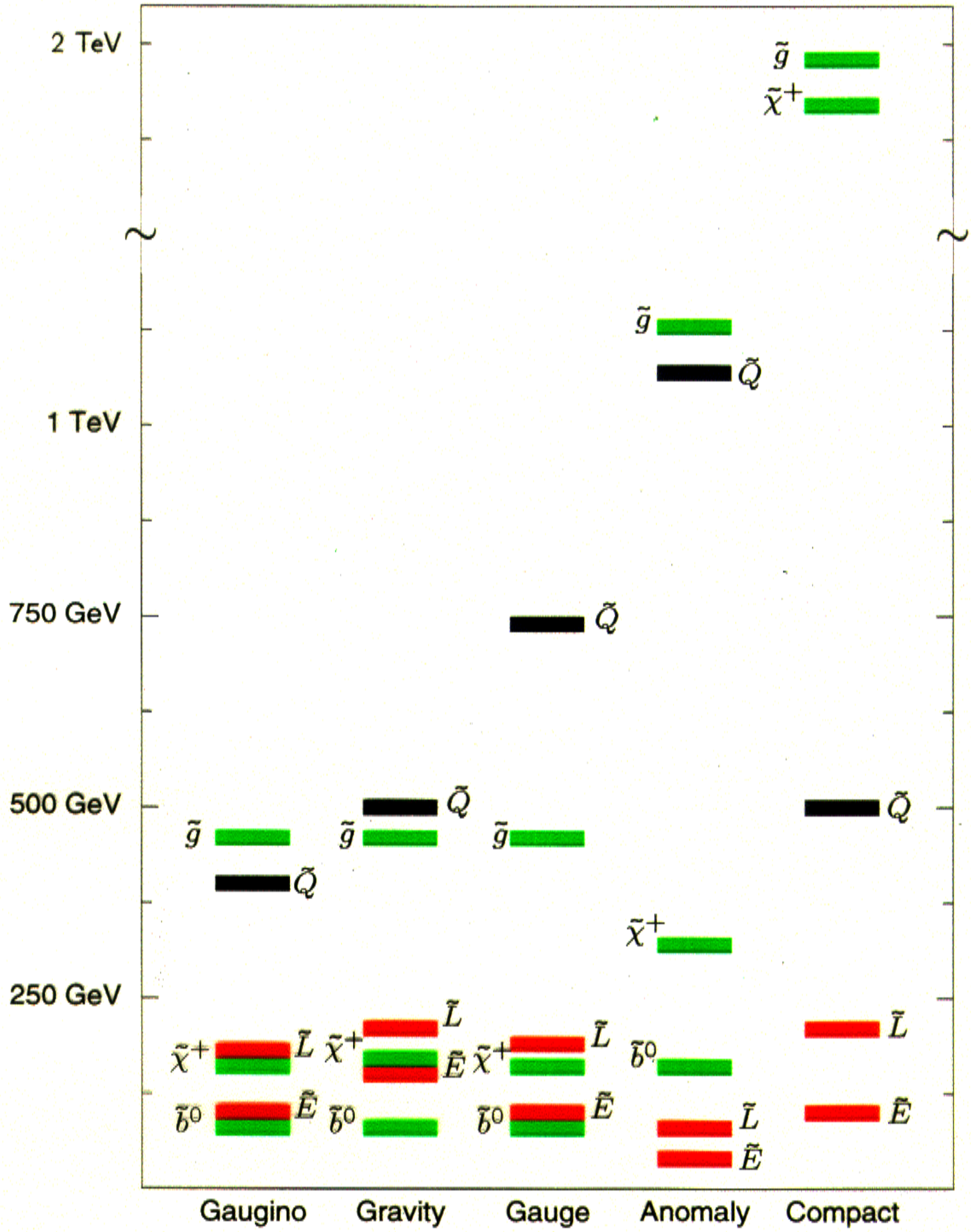
$\tilde{\tau}_1 \to \tau + \tilde{G} = \tau + \not{E}$

AMSB:

$\tilde{\chi}_1^\pm \gtrsim \tilde{\chi}_1^0$

$\tilde{\chi}_1^\pm \to \tilde{\chi}_1^0 + \pi$ soft

Peskin
Pard. e.a



Tsukamoto ea

F

(iii) mSUGRA sum rules:

masses
decay modes
production processes
} 5 parameters

$m_0,\ M_{1/2},\ A_0,\ \mathrm{sgn}\,\mu,\ \mathrm{tg}\,\beta$

gaugino masses: $M_1 / M_2 = \frac{5}{3}\,\mathrm{tg}^2 \vartheta_W$

slepton / gaugino: $m^2(\tilde{\ell}_L) - m^2(\tilde{\ell}_R) = \alpha M^2_{1/2} - \frac{1}{2}(1-4s^2_W)\,c_{2\beta}\,M^2_Z$

...

(iv) reconstruction of fund. SUSY theory:

[basic param. low scale] $\Longrightarrow$ (RGE) [fund. theory high scale]

bottom-up approach: much better discriminative
[ps – fix points]
than top-down [~ LHC]

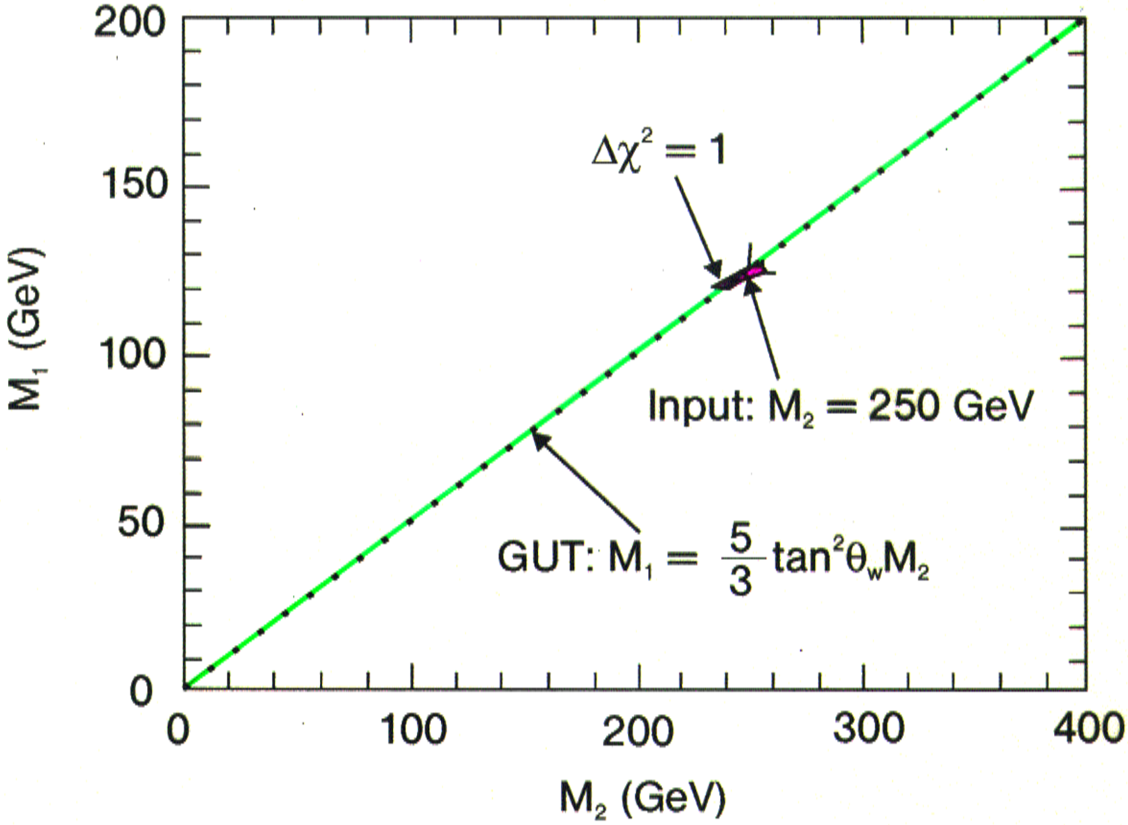
F: mSUGRA vs. $\tilde{g}$MSB
vs. GMSB

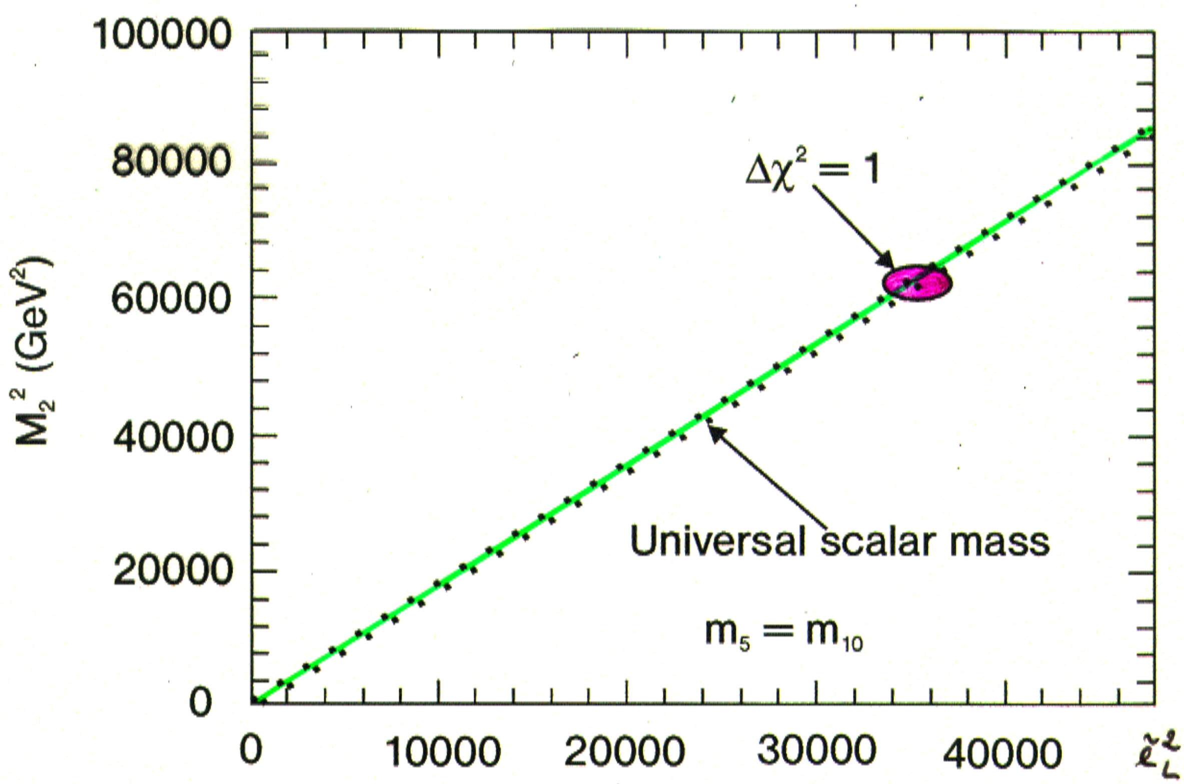
[JLC / NLC / TESLA + CLIC promise acc. reconstr. at high scale]

mSUGRA fit:

gaugino $M_{1/2}$ = 200 GeV → 200.0 ± 0.1 GeV
scalar m_0 = 160 GeV → 159.9 ± 0.1 GeV

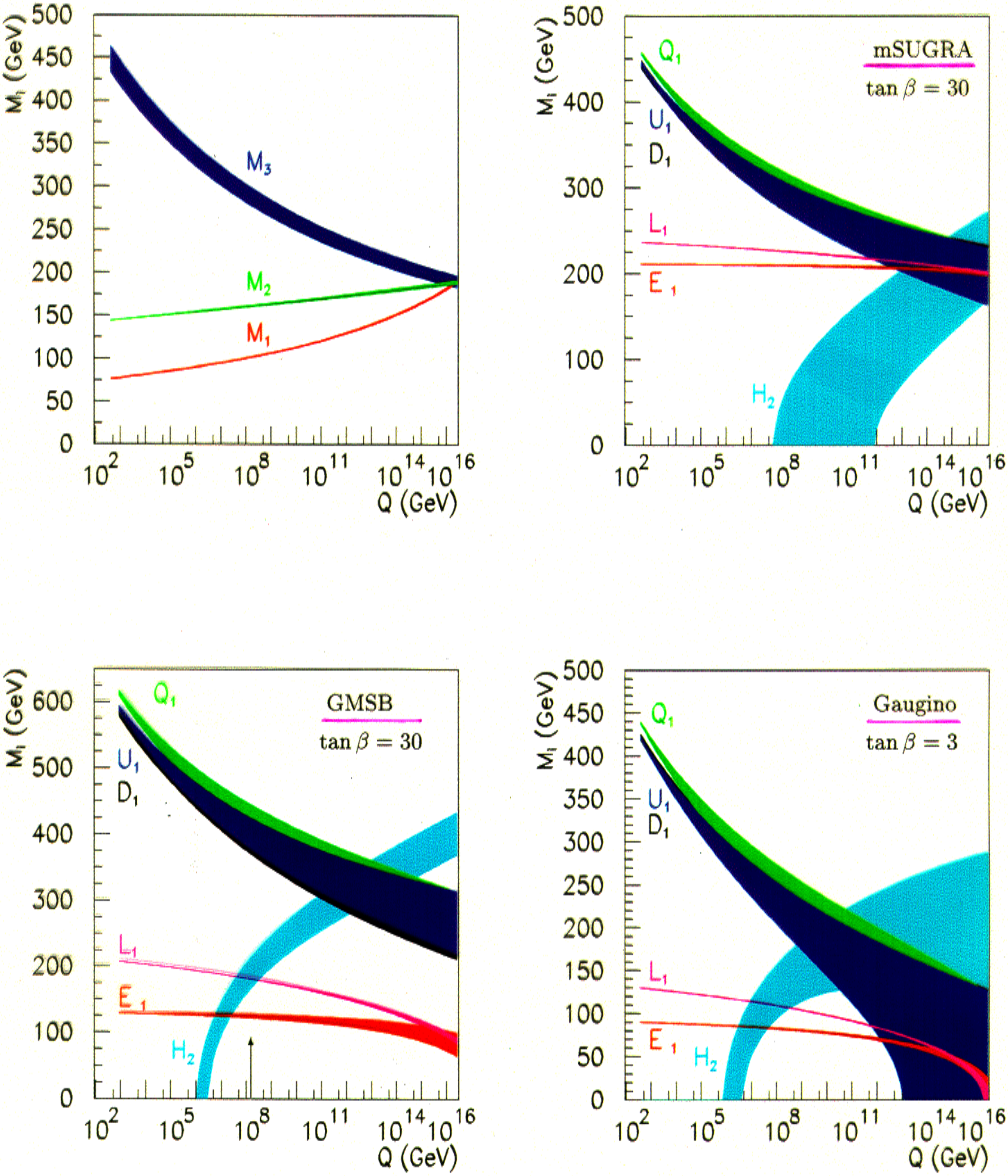
Tsukamoto et al





$\tilde{e}_L^2 - \tilde{e}_R^2$

Blair
Porod, Z



The high precision which can be achieved at e^+e^- colliders, opens perspectives on particle physics near the Planck scale.

2c) EXTRA SPACE DIMENSIONS

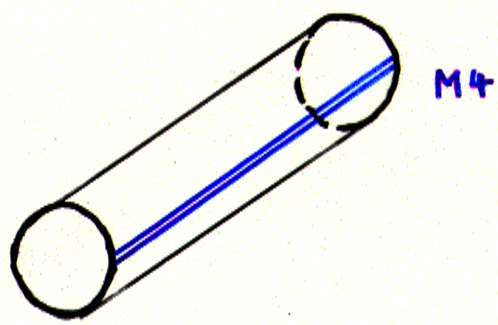
Arkani-Hamed

motivation:
- consistency of string / M theory
- m ~ - unification GUT + gravity
- removing hierarchy problem

space-time structure:

compactified dimensions:

$M_S^{n+2} R^n = M_{PL}^2$

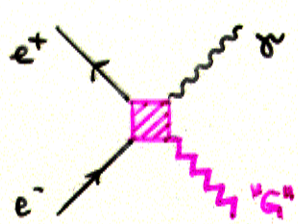


The maxi / midi / mini parade:

maxi: $M_S \sim$ TeV $R \sim$ mm ... μm ... :: gravity in bulk

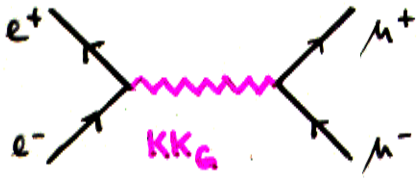
(i) missing $\not{E}$: $e^+e^- \to \gamma + $ "$G(m)$" $= \gamma + \not{E}$

Peskin



n	LHC / -2	J/N/T	CLIC
[2]	12.5 / ⟨25⟩	7.7 TeV	⟨40 TeV⟩
4	7.5 / ⟨15⟩	4.5 TeV	⟨22 TeV⟩
6	6 / ⟨12⟩	3.1 TeV	⟨16 TeV⟩

(ii) Kaluza - Klein CI : $e^+e^- \to f\bar{f}$ Hewett



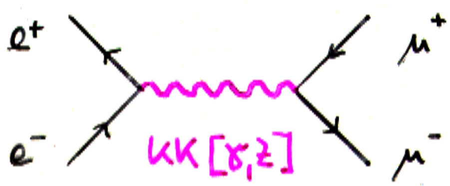
contact interactions spin = 2

sensitivity $M_S \sim 8 \to 40$ TeV

$\gamma\gamma \to W^+W^-$: 12 TeV Rizzo

midi : $M_S \sim 10^7$ GeV $R \sim \text{TeV}^{-1}$ :: gauge field in bulk

KK gauge towers : Antoniadis



JNT : spin 1 CI

CLIC : RESON. PEAK F

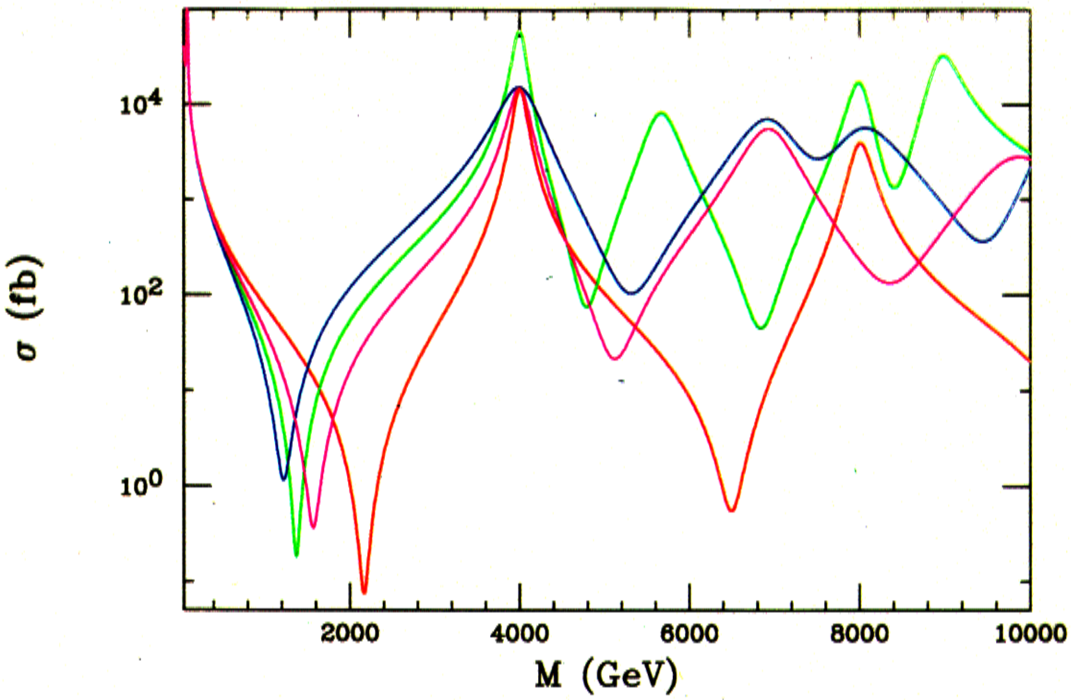
mini : $M_S \lessdot M_{PL}$ $R \gtrsim M_{PL}^{-1}$ :: gravity in bulk

RS : loc. gravity on 2nd brane

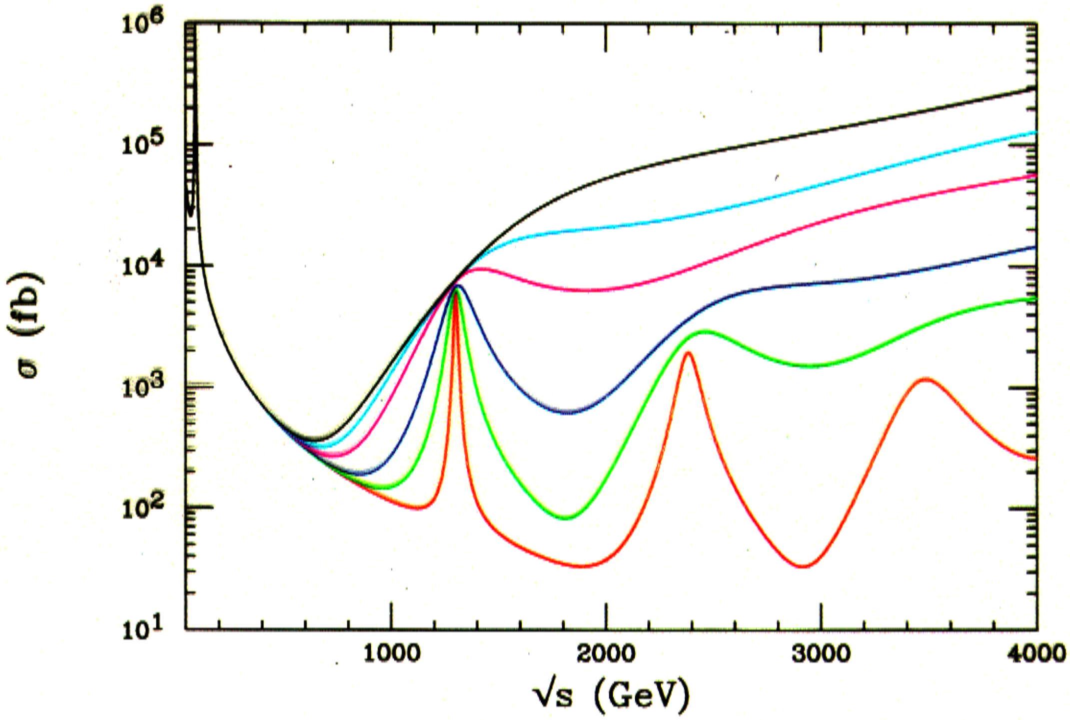
graviton towers : RESON. PEAK's F Rizzo

Through angular distributions, JLC / NLC / TESLA can give valuable information on physical nature of KK towers; CLIC goes to maxim. limits.

Rizzo



Cross section for the process $e^+e^- \to \mu^+\mu^-$ for several models with $d = 2$ assuming $M_1 = 4$ TeV. The red(green,blue,purple) curve corresponds to the $S^1/Z_2(Z_2 \times Z_2,\ Z_{3,6},\ S^2)$ compactifications.

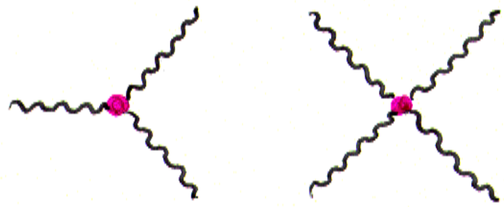


Cross section for $e^+e^- \to \mu^+\mu^-$ including the exchange of KK gravitons, taking the mass of the first mode to be 1.3 TeV, as a function of energy. From top to bottom the curves correspond to c=1.0, 0.7, 0.5, 0.3, 0.2, 0.1.

3 a) GAUGE THEORIES

a) **SM = $SU_3 \times SU_2 \times U_1$** : forces are mediated by abelian and non-abelian gauge fields

$SU_2 \times U_1$ self-interactions :



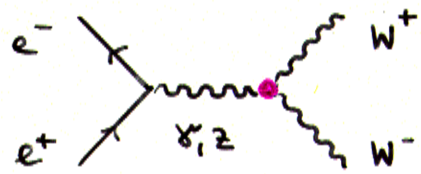
SM deviations
$\Delta \sim M_W^2 / \Lambda_*^2$

→ elw static param. : $\gamma W^+ W^-$ etc

monopole charge : e
magn. dipole mom. : $2 \times e / 2M_W$
el. quadrup. mom. : $-e / M_W^2$

measurement:

$\Delta\sigma/\sigma \sim \Delta \times \gamma^2$



LC 500 : $\varkappa, \lambda$
$\Delta < 2 - 3 \times 10^{-4}$

F

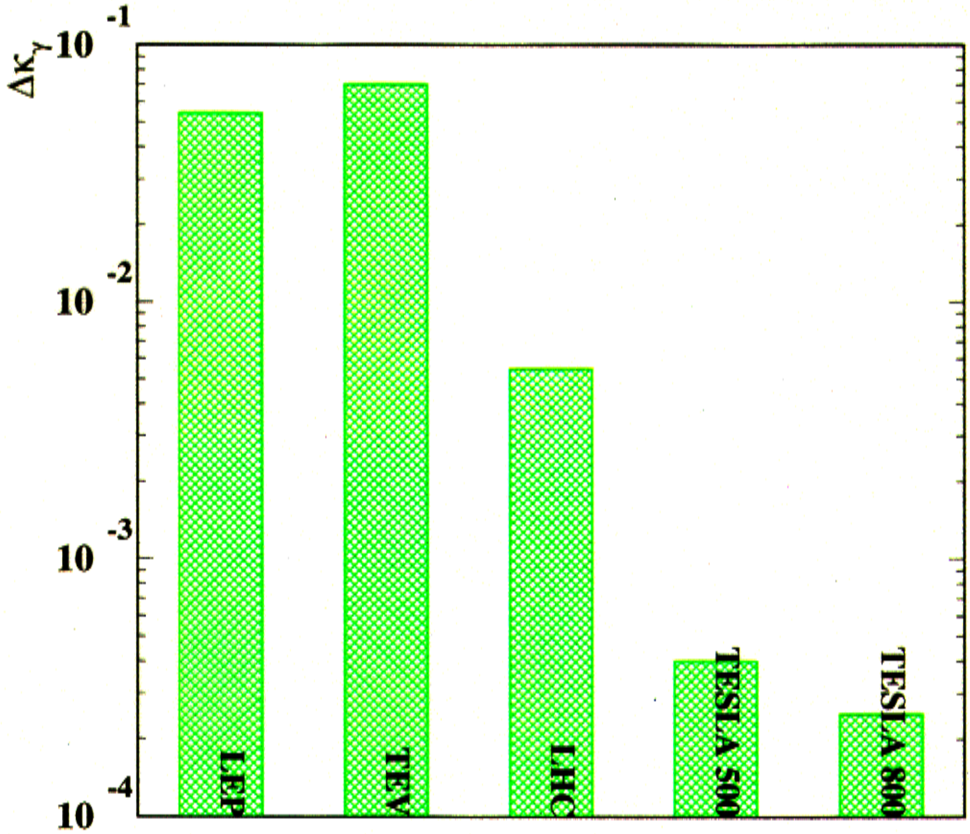
b) **EXTENDED GAUGE SYMMETRIES**

$E_6 \to SO_{10} \times U_1 \to SU_5 \times U_1 \times U_1$
$\to SU_3 \times SU_2 \times U_1 \times U_1'$

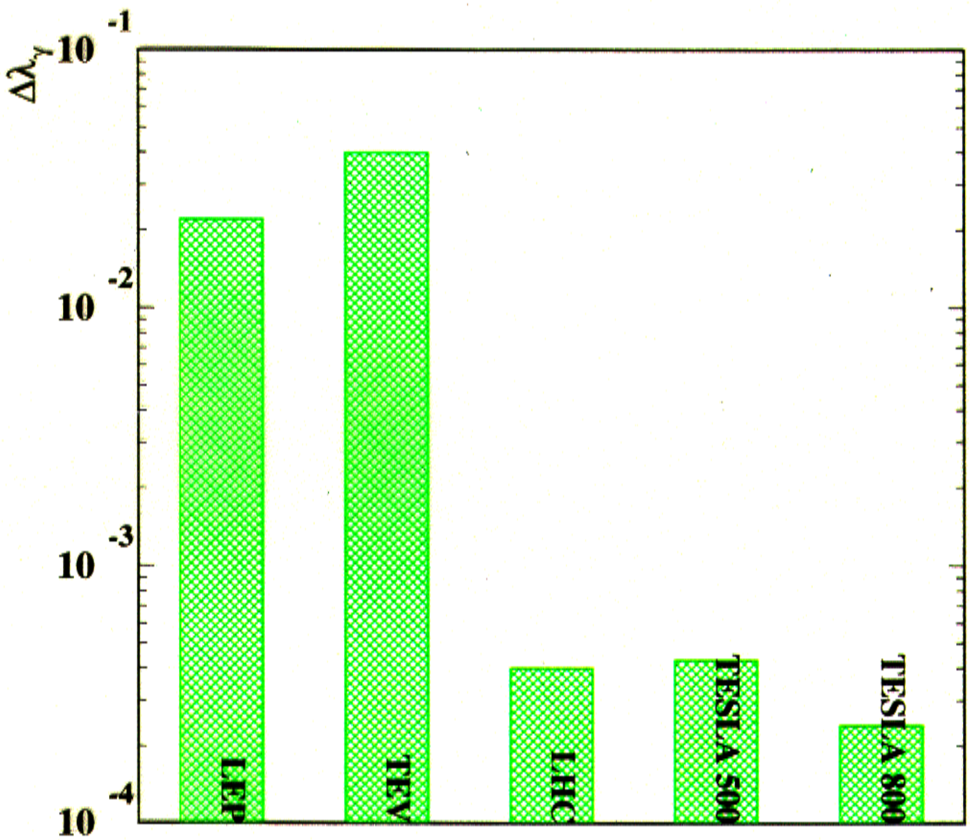
- Z' with mass $M(Z') \sim \mathcal{O}(\text{TeV})$
- 27 plet : $\begin{bmatrix} \nu_e \\ e^- \end{bmatrix}_L$ ν_{eR} e^-_R $\begin{bmatrix} N_E \\ E^- \end{bmatrix}_L$ $\begin{bmatrix} N_E \\ E^- \end{bmatrix}_R$ n_{eL}

  $\begin{bmatrix} u \\ d \end{bmatrix}_L$ u_R d_R D_L D_R

Mönig ea

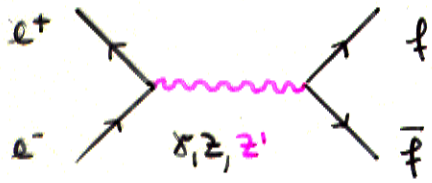


$\Delta\kappa_\gamma$
10^{-1}
10^{-2}
10^{-3}
10^{-4}
LEP
TEV
LHC
TESLA 500
TESLA 800



$\Delta\lambda_\gamma$
10^{-1}
10^{-2}
10^{-3}
10^{-4}
LEP
TEV
LHC
TESLA 500
TESLA 800

new gauge boson Z':



LHC|-2 : $M_{Z'} \sim 5/10$ TeV

$\sqrt{s}$	E(6)
500 GeV	5 - 7 TeV
800 GeV	8 - 11 TeV
5 TeV	~ 50 TeV

CHARGES :
F

‖ LC allows for measurement of U(1)' charges and opens sensitivity window to Z' masses in multi - TeV range.

c) QCD :

running coupling $\alpha_s(Q)$ ...

" half - way to infinity "

$\Delta\alpha_s(M_Z^2) \to 0.001$

F

d) GigaZ :

2×10^9 Z bosons ~ 100 x LEP1

polarized e^+ and e^- beams

Mönig

LR asymmetry : $A_{LR} = \frac{2(1-4s_e^2)}{1+(1-4s_e^2)^2}$

$\Delta \sin^2\theta_{eff,\ell} \approx 1 \times 10^{-5}$

loop test of the Higgs field :

$\Delta' M_H \approx 6\,\%$

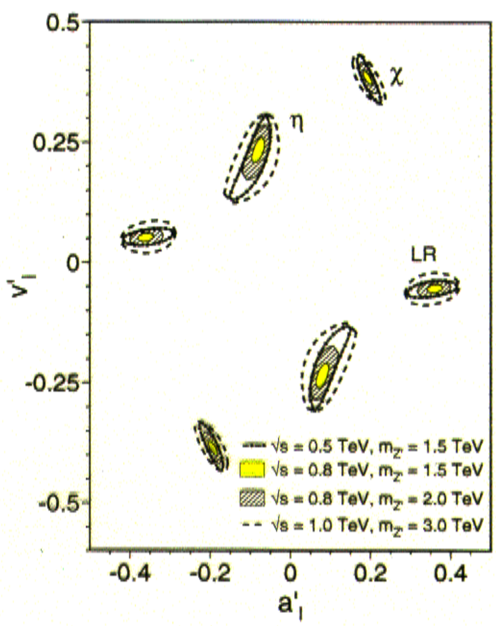
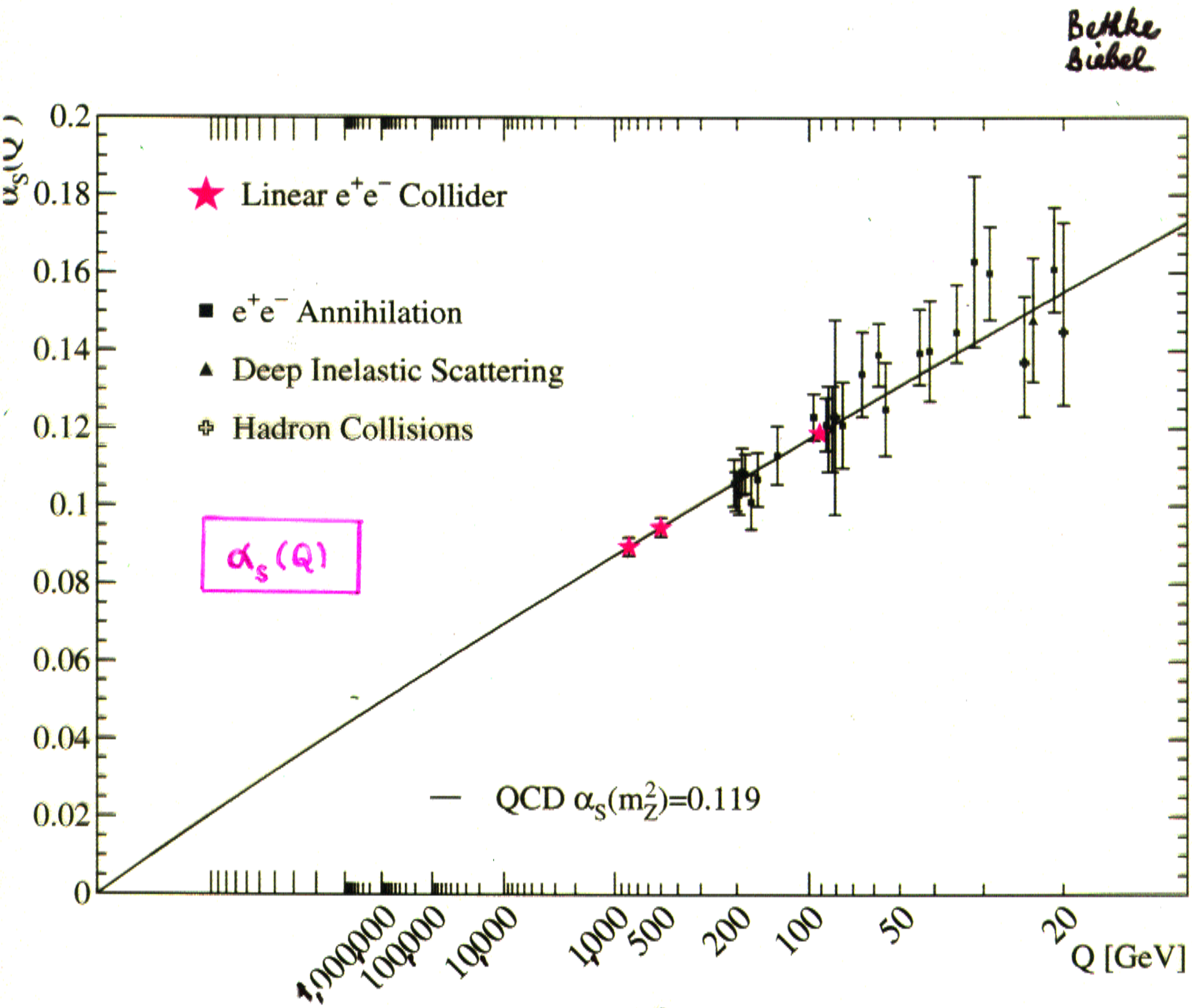


Figure 9: Resolution power for different $m_{Z'}$ (95% CL) based on measurements of leptonic observables at $\sqrt{s}$=500 GeV, 800 GeV, 1 TeV with a luminosity $\mathcal{L}_{int}$ =1000 fb^{-1}. The leptonic couplings of the Z′ correspond to the χ, η or LR model.



Bethke
Biebel
$\alpha_s(Q)$
Linear e^+e^- Collider
e^+e^- Annihilation
Deep Inelastic Scattering
Hadron Collisions
$\alpha_s(Q)$
QCD $\alpha_s(m_Z^2)$=0.119
Q [GeV]

3 b) TOP QUARK

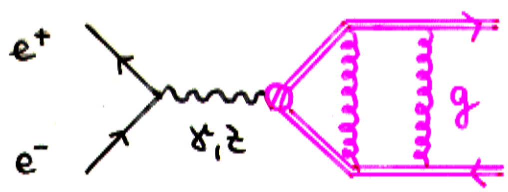
high-precision measurem. of t properties : mass
stat. elw param.
decay parameters

→ test of elw symmetry brkg at qu level

$G_F,\ M_Z,\ \sin^2\vartheta_W\,;\ M_t \ \to\ M_H$

→ $M_t \sim v/\sqrt{2}$ maximal mass in SM fermion sector :
key rôle in flavor dynamics, ...

M_t max precision : $e^+e^- \to t\bar{t}$ excitation curve near threshold }



$\sigma_{t\bar{t}} \sim \beta_t \sim \sqrt{s-4M_t^2}$ F

⊖ width

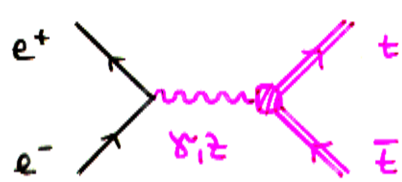
⊕ g ladder Sumino, Hoang ea

$\Delta M_t \lesssim 200$ MeV
$\Delta M_t / M_t \lesssim 1‰$
F

most precise mass in q sector

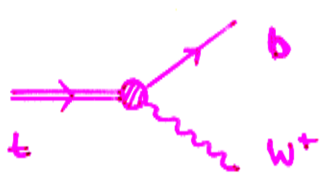
$\Delta\Gamma_t/\Gamma_t \lesssim 0.05$ S-P interf Kühn ea
$t\bar{t}g_{IR}$ Orr

ELW

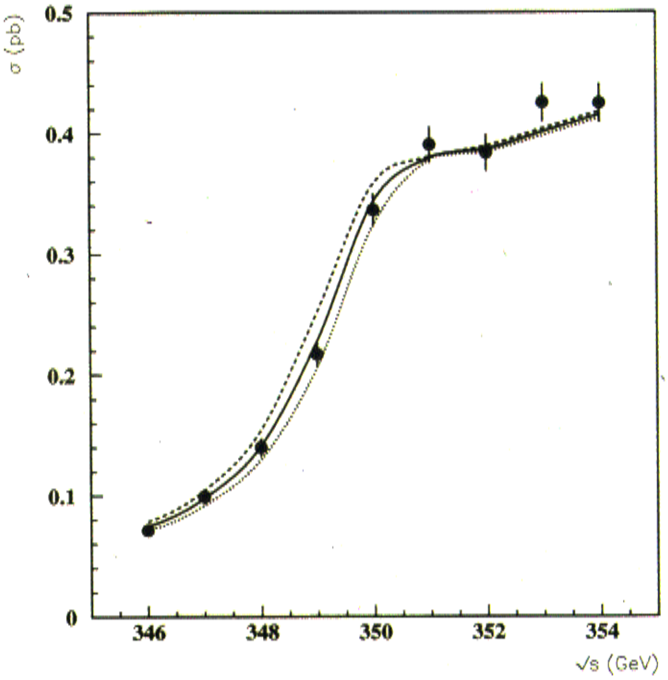


magn. dipole mom. $\lesssim 1.1 \times 10^{-2}$
el. dipole ~~CP~~ mom. $\lesssim 4 \times 10^{-19}$ ecm

Bernreuther



Michel parameter :
V+A / V−A $\lesssim 1.2 \times 10^{-2}$



top – Wg

Figure 3.3.3: *Excitation curve of $t\bar{t}$ quarks including initial-state radiation and beamstrahlung [21]. The errors of the data points correspond to an integrated luminosity of $\int \mathcal{L} = 100\ fb^{-1}$. The dotted curves indicate shifts of the top mass by ± 100 MeV.*

4. CONCLUSIONS

1.) Higgs mechanism and elw symmetry breaking

- essential elements of Higgs mechanism can be established;
- strong WW interactions can be studied throughout threshold region: $\Lambda_* \sim 3$ TeV at 500 GeV; at 5 TeV deep in resonance region;

2.) Supersymmetry

- spectrum can be analyzed comprehensively ~ 1 TeV, method robust;
- SUSY breaking mechanism analyzed experimentally;
- reconstruction of fundam. theory at scale $\sim M_{PL}$ where particle physics $\sim$ gravity;

3.) Extra space dimensions

- structure of space-time probed experimentally at short distances;

4.) Elw and Strg gauge theories

- non-abelian gauge symmetries of forces established at high accuracy;

- extended gauge symmetric theories can be explored in detail, at 5 TeV window to ~ 50 TeV;

Top quark

- profile of key element to flavor physics can be studied with high precision

> all phases of an e^+e^- linear collider project
>
> $\sqrt{s}$ = 500 GeV / 1 TeV // 5 TeV
>
> promise new deep insight into microscopic physics